The **HOW AND WHY** *Wonder Book of*

VOLCANOES

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THE HOW AND WHY BOOK OF

VOLCANOES

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Introduction

Volcanoes fascinate and intrigue most people because of the excitement and occasional devastation they produce. This How and Why volume describes the variations in volcanic eruptions and the wide range of results associated with volcanoes. It also attempts to explain the causes and origin of all these effects. The causes are now at least partially understood and although the explanation is complex the basic idea may be grasped by quite young children.

The materials which are emitted by volcanoes often have considerable effects on the scenery, rock type, economic development and the entire way of life of the affected area. Volcanic regions range from the barren lava and ash fields which occur in many places to the rich cultivation found in Java or on the slopes of Etna. Long after volcanoes cease to erupt they can still affect the local way of life, not only by the provision of soil for farming when the lava has weathered for a few hundred years, but also by the creation of tourist attractions such as geysers, and the formation of deposits of metals. Even in inactive lands such as Britain or U.S.A. (excluding Alaska and Hawaii) the past effects of vulcanism may be noticed, as for example at Giant's Causeway or in Yellowstone National Park.

This volume quotes examples from many parts of the world although present-day activity is restricted to certain well defined regions on the earth's crust.

Roy Woodcock
Godalming, 1974

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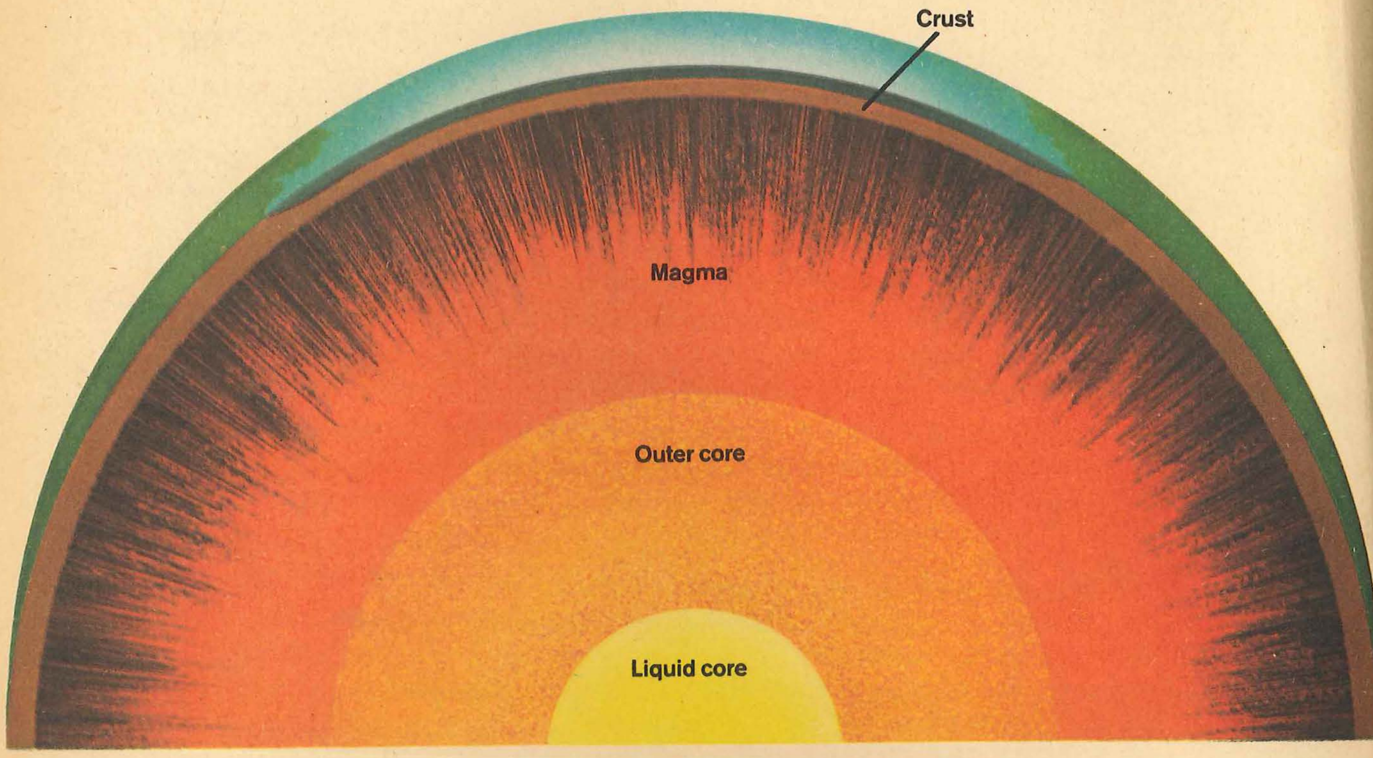


A cross-section through the earth's crust.

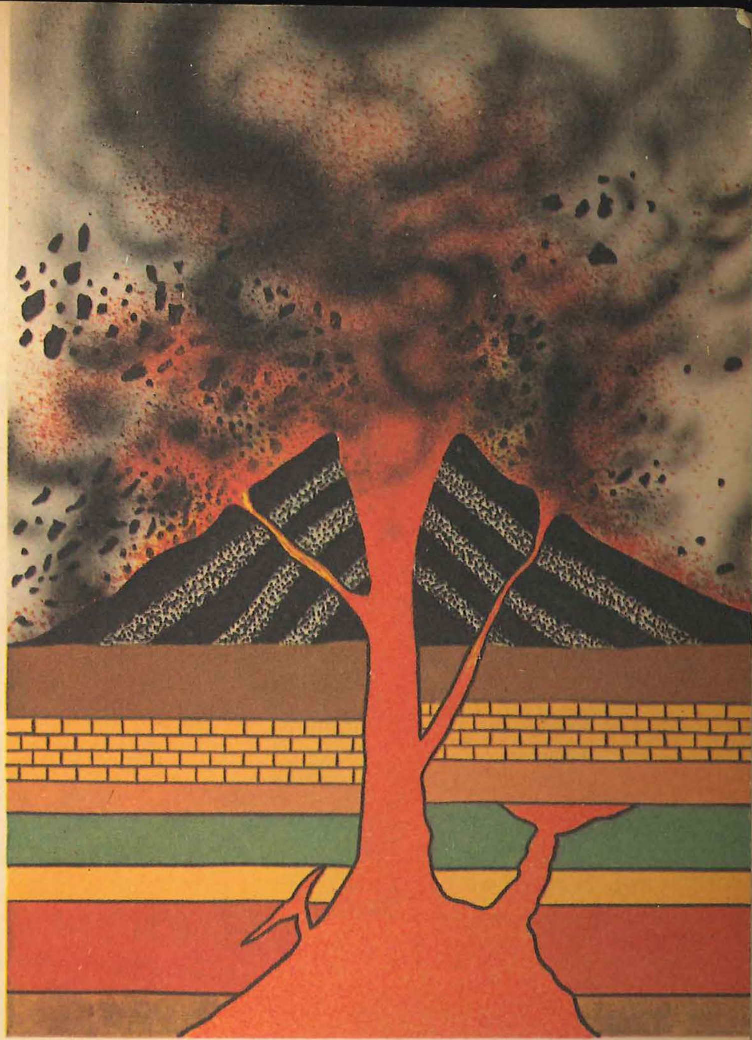
Eruptions and Types of Volcanoes

The temperature of the earth increases steadily moving from the crust in towards the centre. At the centre the rocks are so hot that they are liquid. Moving outwards from this liquid core, the rocks become steadily cooler, but in some places, just a few kilometres below the surface, the rocks may still be hot enough to melt. If this molten rock or magma can force its way to the surface through a weakness in the outer shell or crust, a volcano may be formed. The depth from which the volcanic material erupts will often determine the chemical content of the rocks which are formed. This is why volcanic rocks are very varied in type.

Why do volcanoes erupt?

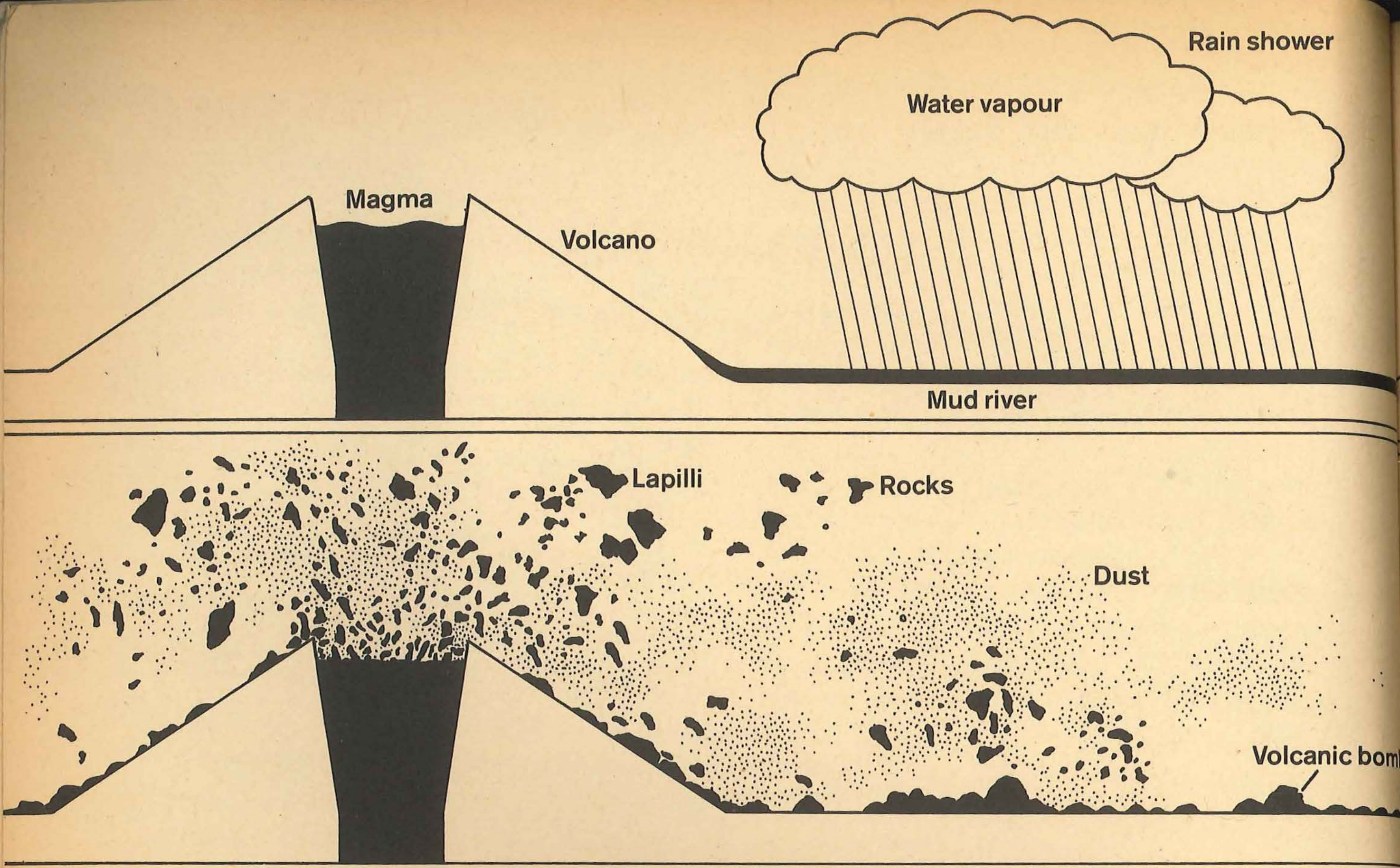
The heat of the earth enables the rock to melt and so a reservoir of liquid rock, called magma, is held some distance below the surface. The magma is hot and similar to a kettle of water which is trying to boil over. If this hot liquid mass is able to force its way out through a weakness in the crust, a volcano will result. If gentle upwards pressure is all that is required to allow the magma to escape, the volcano will be fairly quiet. If, on the other hand, tremendous energy is required to force a way out, a powerful eruption will result. The energy required for this will be much greater than the largest nuclear explosions.

When the magma emerges it is called lava. If the lava is rich in silica, which is a very common mineral in the earth's crust, it will be acidic. This means the lava will be sticky or viscous, rather like thick treacle. This acidic lava will flow slowly whereas lava which is basic, containing much less silica, will be more fluid. Some lavas are so slow flowing that they may be approached quite safely by spectators, as happened during the Etna eruptions of 1971. In addition to the lava which oozes out of the crater, solid lumps of rock may also be blown out if there is an explosion.



Right—a high pressure eruptior

Some lava flows so slowly that it may be approached quite safely by spectators and scientists.



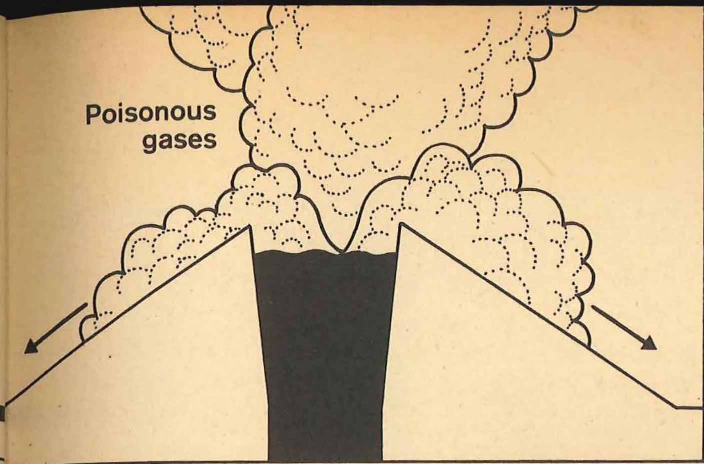
Some of the after-effects of volcanic action.

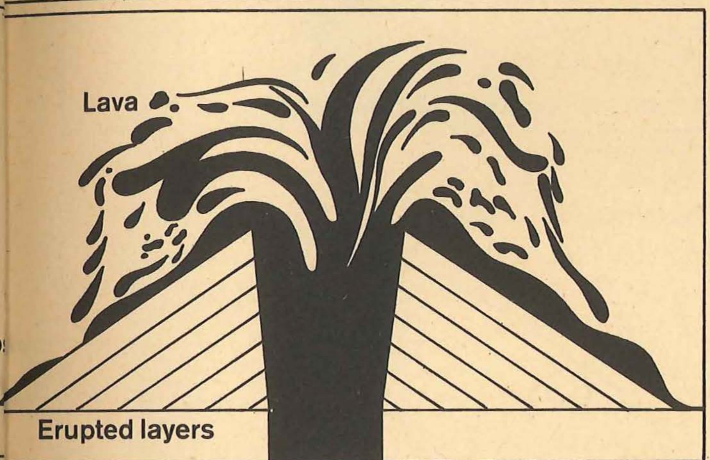
What are the products of an eruption?

A volcanic eruption may emit gases, flowing lava or solids. The gases include hydrogen, oxygen, chlorine and much water vapour. A rain shower often follows eruptions, because of the water vapour which has emerged from the crater. The heavy rainfall will occasionally mix with volcanic ash and form a mud river. In Iceland there have been eruptions underneath ice caps which have melted the ice and created muddy rivers.

Sulphurous fumes can often be unpleasant or even dangerous in and around craters, e.g. Etna or Vesuvius. Much more dangerous, though rather infrequent, are the clouds of hot steam and poisonous gases which are associated with some eruptions. These deadly clouds, called by their French name of nuées ardentes, roll down the hillside at up to 320 kilometres per hour, destroying everything en route.

In addition to gases, most volcanoes pour out some lava which oozes gently from the crater. The flow of lava may only continue for minutes, or for days, and may be acidic or basic. Acidic lavas are between 65 and 75 per cent silica, and basic lavas contain less than 50 per cent of silica. Basic lavas flow freely over the countryside and form hills with only gentle gradients, whereas acidic lavas, which tend to be more explosive, flow slowly and will usually form steep sided hills. Volcanoes may produce basic lava during one eruption, but acidic material at another date. The chemical content of the lava seems to be determined by the length of time between eruptions. If there is a long gap between eruptions, the lava is

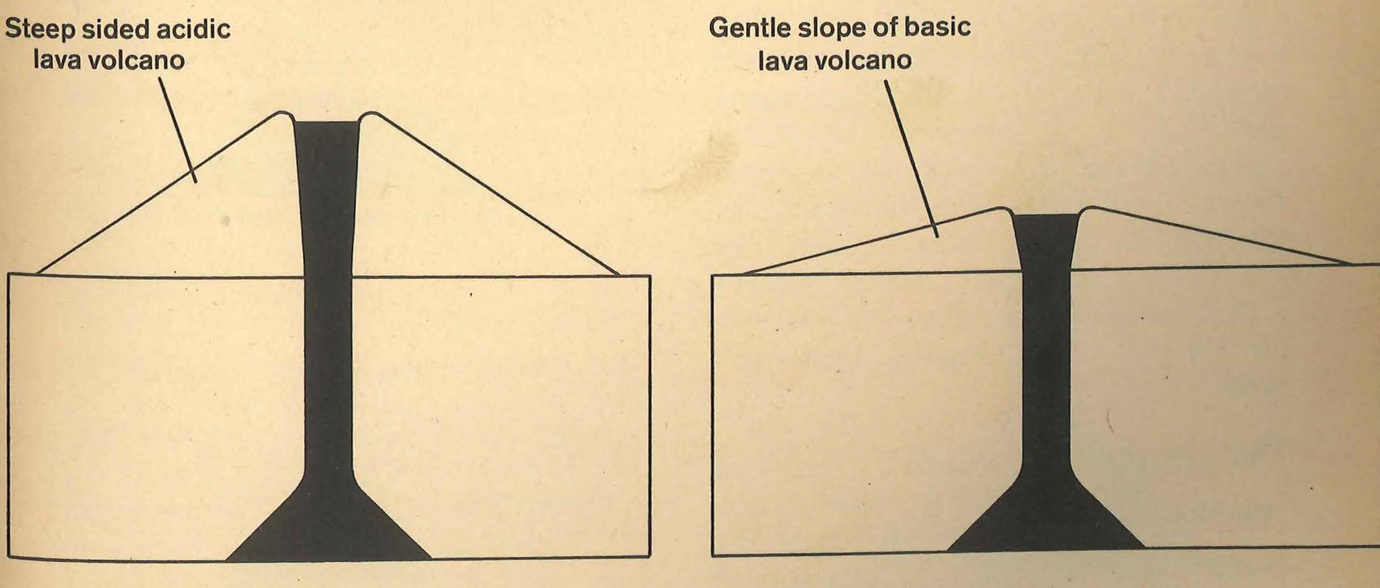




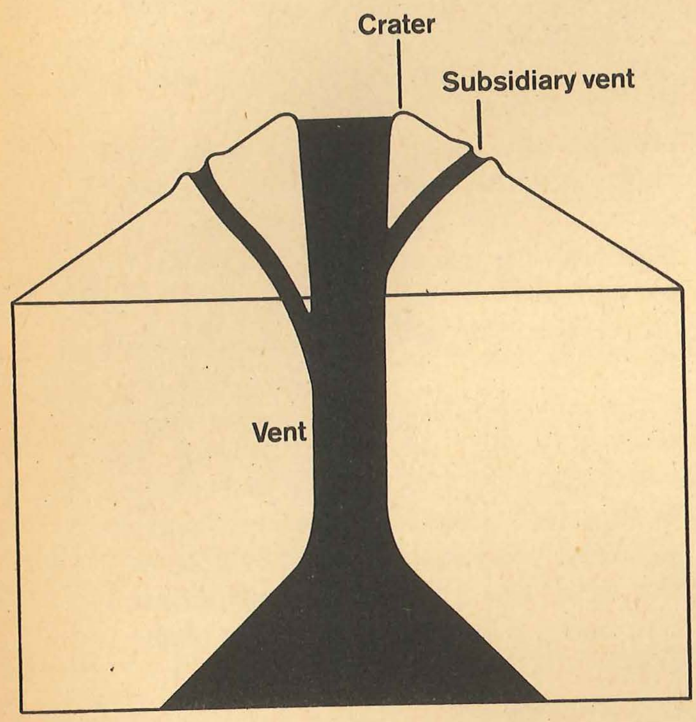
usually acidic, and the activity is more violent. This is because the acidic lava is a greater obstacle, and a bigger explosion is required to open the vent.

The other solid materials coming out from the volcanoes are blown out by the explosion. These are called pyroclastics and may range in size from rocks several centimetres in diameter down to tiny particles of dust. All particles blown into the air will be carried downwind as they fall. The larger cinders, called lapilli, fall near the crater, but the dust particles may travel several miles. Lumps of liquid lava may also be blown out of the crater and they solidify into pear shapes as they fall. These are volcanic bombs. All these pyroclastic materials accumulate and are eventually consolidated into rocks which help to build volcanic hills.

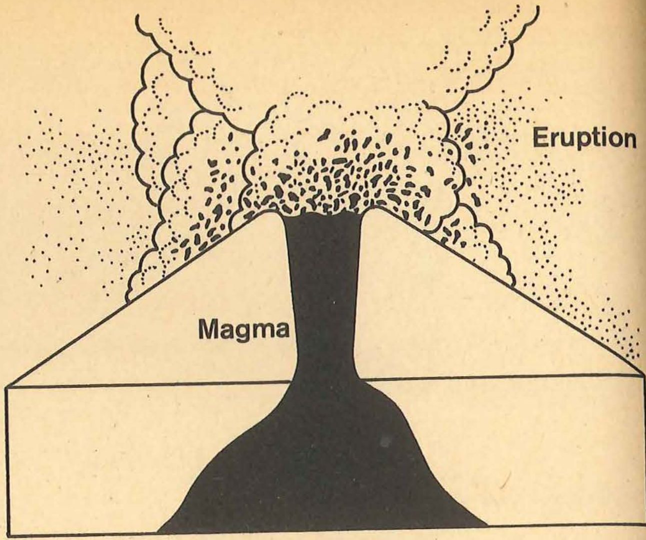
The shape of the cone varies according to the acidity of the lava.

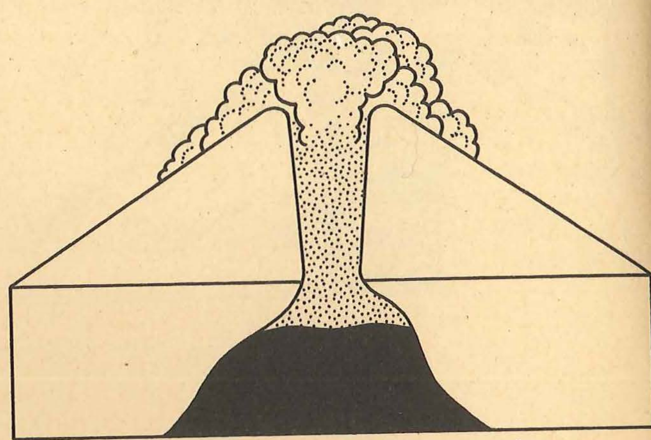


The diagrams on the right show how a caldera is formed.

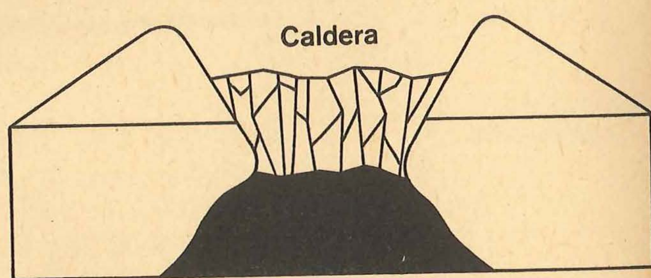


Many volcanoes develop secondary or subsidiary cones on the sides of the mountains.



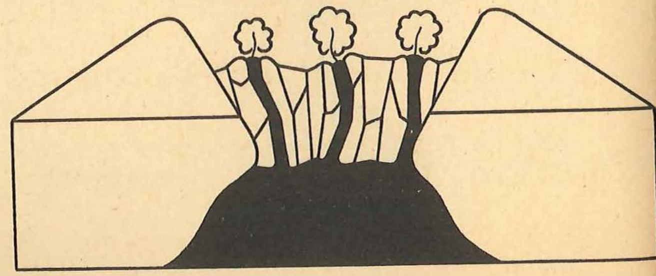


Violent eruptions have ceased



Top of cone has sunk into the magma

Caldera with new cones



Why are volcanoes cone shaped?

All the products of the eruption emerge via a pipe or tube called the vent, the top of which is the crater. The materials ejected, whether lava or pyroclastic, tend to accumulate most rapidly near the crater. A hill begins to form after a few eruptions, and thus an overgrown mole hill will be created. After many years and many eruptions a typical volcanic cone shape may reach up to several hundred or even thousands of metres. The largest volcanic cone is in the Hawaiian Islands, where Mauna Loa is actually bigger than Mt. Everest, though half of its height is below sea level.

How big is the crater?

The eruptive materials move up the vent and out through the crater, which is usually at the top of the hill. Some craters are quite small, only a few metres in diameter, and when the volcano is erupting, the crater is full of bubbling lava which is overflowing like a saucepan of milk boiling over. Other craters, especially on big and old volcanoes, may be much larger. In these large craters it is possible for some eruptive activity to occur in one place whilst it is quite safe for spectators to watch from nearby, but actually inside the crater. Teams of geologists frequently camp inside craters in order to study the new rocks which are appearing up the vent. In addition to erupting through only a small hole in quite a large crater, it is possible for volcanoes to open up new craters on the sides of the hill, not necessarily at the top. These subsidiary vents can occur anywhere. They are common on most large volcanoes and Etna, for example, has over 200, including those from the latest eruptions in 1971 and 1974. These subsidiary cones are common and yet Cotopaxi, the highest active volcano in the world (6,200 metres), only erupts through its crater at the top of the cone.

Most craters are the result of explosions blowing out the rock on the surface, to create a hole. They are generally less than a kilometre in diameter and up to 150 metres in depth. The largest active crater is in Aniakchak in Alaska. This is nearly 9 kilometres in diameter.

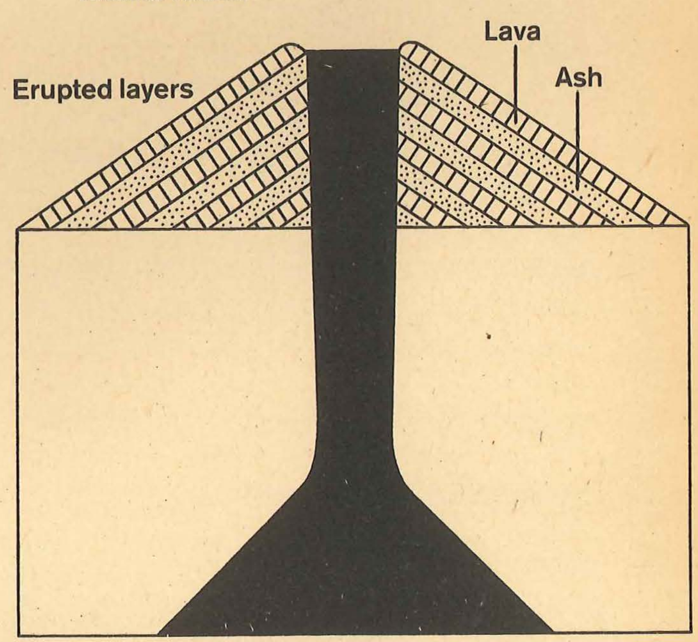
Large craters are sometimes called calderas. These are caused by explosions or collapse, and result in the summit or peak of the volcano collapsing in on itself. This creates what is really an overgrown crater. One of the biggest examples is Crater Lake in Oregon, U.S.A., which occupies a caldera 9 kilometres in diameter and over 600 metres deep.

Are all volcanoes similar?

A standard type of volcano will explode in order to blow out a passage up which the lava will then flow. When the flow of lava ceases, the crater will be blocked. An explosion will be necessary to open up the vent after which the next lava will flow. Alternating layers of pyroclastic material from the explosions and lava from the effusions will build up a layered volcano. This stratified effect may be disturbed by the formation of subsidiary craters on the sides of the mountain. Each volcano is slightly different from all others in the way in which it behaves, and indeed each volcano is likely to behave in a different manner in successive eruptions. Every volcanic eruption is unique.

In spite of all the differences, the volcanoes can be grouped into a few distinctive types. These are violent explosive volcanoes, those which explode and pour out lava, and those which are fairly quiet, merely pouring out lava from time to time.

Alternate eruptions of ash and lava will form a layered or stratified volcano.



These types of volcanoes are classified into groups which are named after outstanding examples, Mounts Pelée, Vesuvius, Vulcano, Stromboli and Mauna Loa.

The Peléan eruptions pour forth gas, ash and rock. They have the most viscous lava and the most violent explosions, which blow a hole through the solidified lava which has blocked the vent. Gases create the pressure which is able to open up a route for the lava, possibly by blowing off the top of the mountain, like the cork coming off a bottle of champagne.

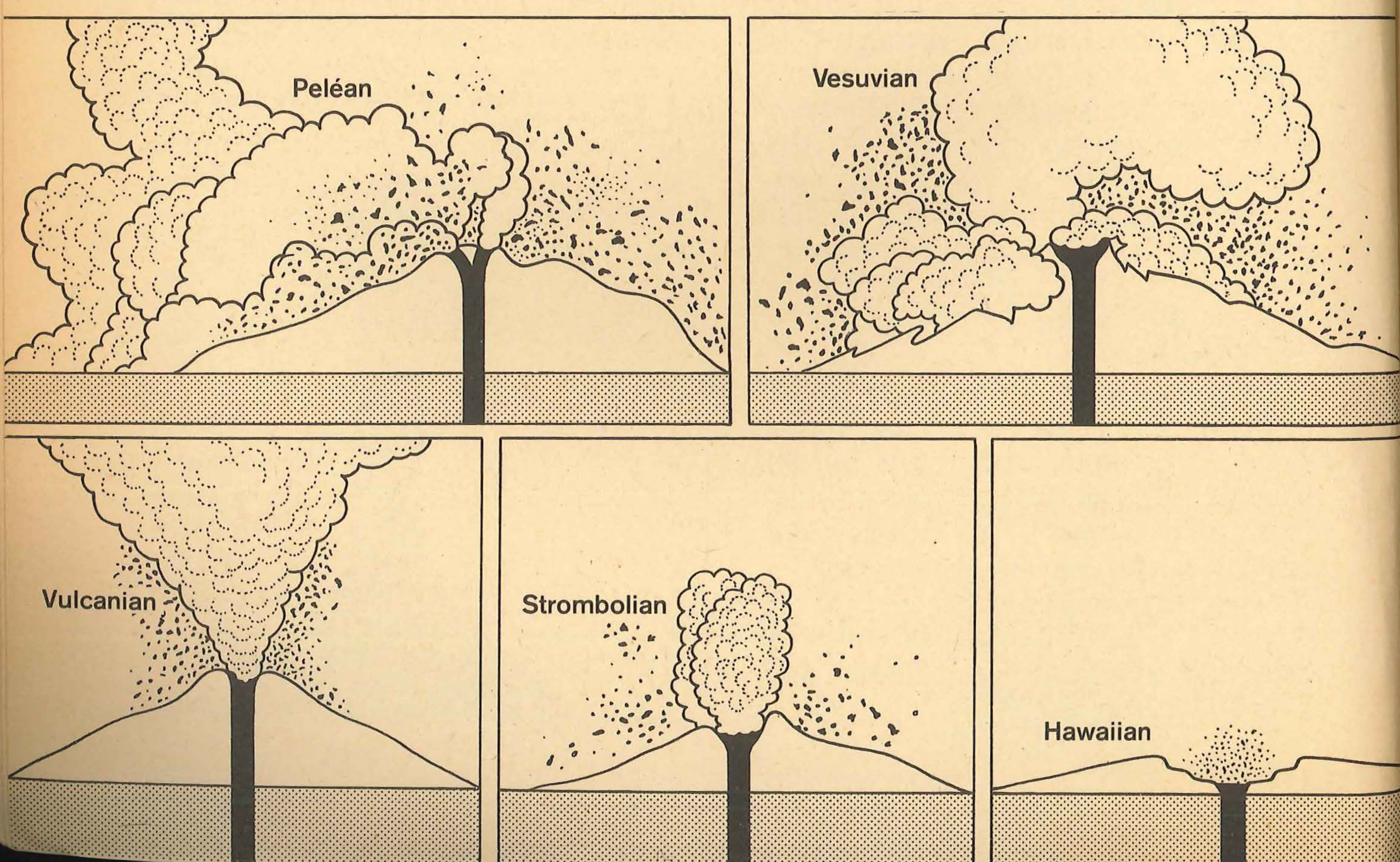
The Vesuvian type is similar to the Vulcanian, but has longer spells of quiescence and hence explodes with greater violence. The top of the mountain may be blown away by the violence of the eruption. Volcanoes resemble safety valves and they need to let off steam occasionally. If there are regular and frequent eruptions, they are quite small. If there are no eruptions for many years, the pressure and energy increase until the volcano boils over or explodes violently.

The Vulcanian type contains viscous acidic lava, and this richly acidic lava is sticky and soon solidifies to form a crust. Beneath this crust, gases accumulate. These gases cause an explosion which blows a hole through the crust enabling the lava to flow again.

Strombolian eruptions are on a small scale, but are more or less continuous. They are intermediate in terms of violence. The emission of gases and small eruptions occur frequently. There is bubbling lava in the crater through which gases escape with small explosions, often blowing bombs into the air.

The largest example of a Hawaiian volcano is Mauna Loa. This type is fairly quiet, with outpourings of mobile basic lava, and only small explosions.

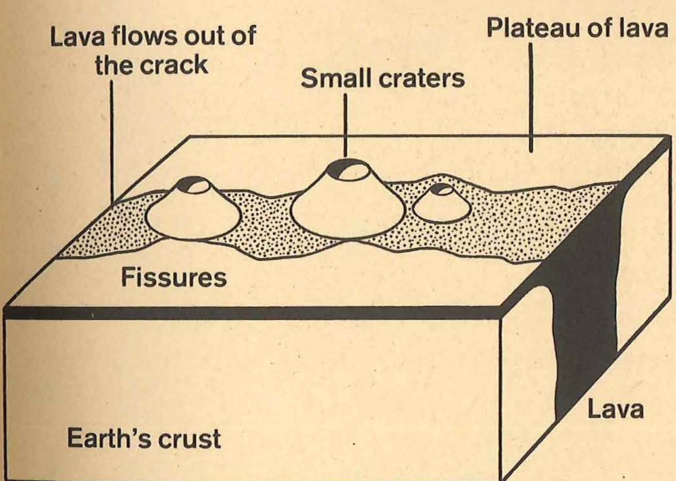
The five main types of volcanoes.



The most basic lava is so free flowing that it travels across the countryside rather like water. It will fill any hollows which exist and will give rise to a flattened plateau like surface. This type of lava does not build mountains as it usually emerges not from vents, but from cracks called fissures.

What are fissure eruptions?

Basic lava often erupts through fissures and forms plateaux and not mountains.



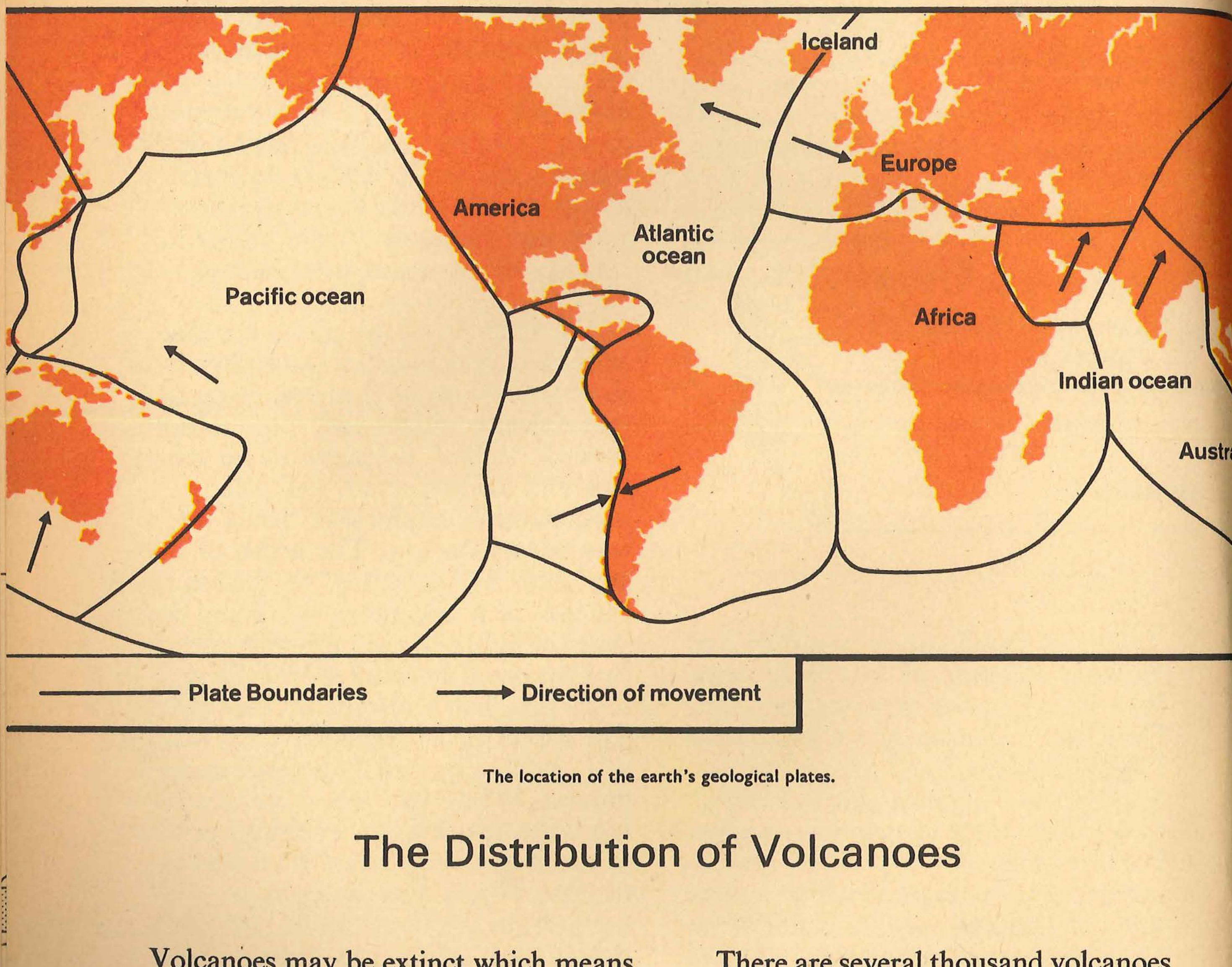
Fissures usually occur in groups and so large amounts of lava may come from them to cover many square miles. The Deccan plateau of India contains 520,000 square kilometres of lava, and in the Snake-Columbia plateau of north west U.S.A. there is a similar expanse. The size of these lava plateaux may be compared with England which has an area of 130,000 square kilometres. There are small fragments of lava plateaux in the British Isles, and these are found in Antrim Mountains, Giant's Causeway, Staffa and Mull. These are all relics of a vast area of lava which included Iceland before the movements of the earth's crust took Iceland away from Britain.

What are geological plates?

Movements of the earth's crust are determined by the movements of the earth's plates. The earth's crust consists of a mosaic pattern of pieces which fit together rather like a jig-saw puzzle. The pieces which comprise the crust are called plates by geologists. The plates move steadily, though very slowly, at rates of one or two centimetres per annum. If the plates move towards each other, they collide and crumple to form new mountain ranges. If they are drifting apart, volcanic rocks emerge from beneath the crust. This is happening along the line of the mid-Atlantic ridge, and this is why 10 per cent of the earth's recent lavas are located in Iceland.

The splitting of the plates has been studied in the Indian Ocean near the southern end of the Red Sea, along the mid-Atlantic ridge and on land in Iceland. Iceland is known to be splitting and drifting apart, and electronic measurement equipment sends light rays across the gap. The width of the gap can be measured to within a fraction of a millimetre, by timing the speed of light rays, and it is now known that the gap is opening at an average of more than half a centimetre each year. The gap does not become a great hole, as it is filled by new lava from underground. Where two plates are spreading outwards, basaltic eruptions occur as the magma only comes from shallow depths. Where two plates meet – for example, in the West Pacific – the volcanoes are acidic and violent. Here there are deep-seated movements caused by one plate submerging beneath another.

Iceland has been formed along the line of the mid-Atlantic ridge, where the plates are parting. Greenland and Europe have drifted apart and Iceland has appeared in the gap. The plates move rather like large slow conveyor belts, and the land masses or continents are mere passengers on these conveyors. They are like rafts floating on water, but are light rocks floating in denser rocks. The continents are not heavy enough to sink, and although the plates will ultimately collide and disappear, the continents will not do so. Instead they will crumple to form fold mountains.



The location of the earth's geological plates.

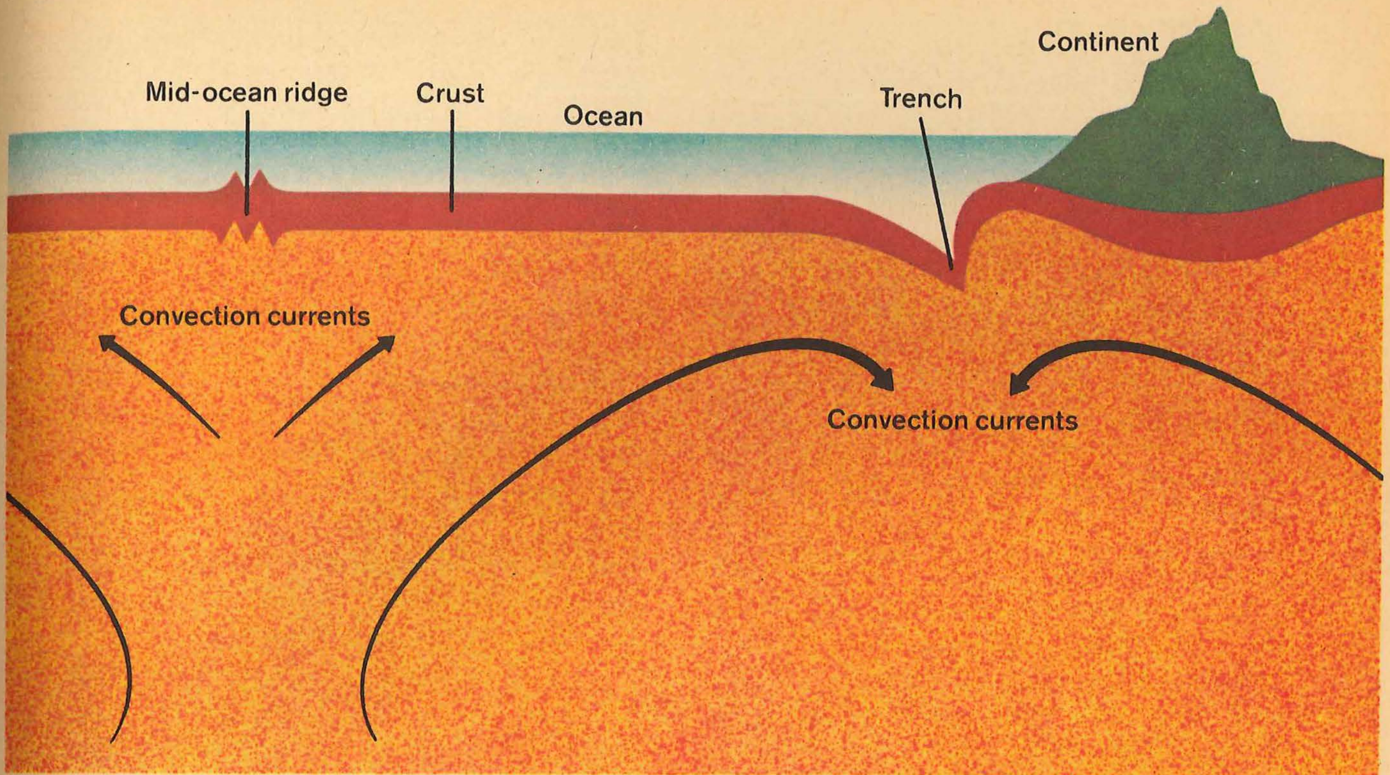
The Distribution of Volcanoes

How numerous are volcanoes?

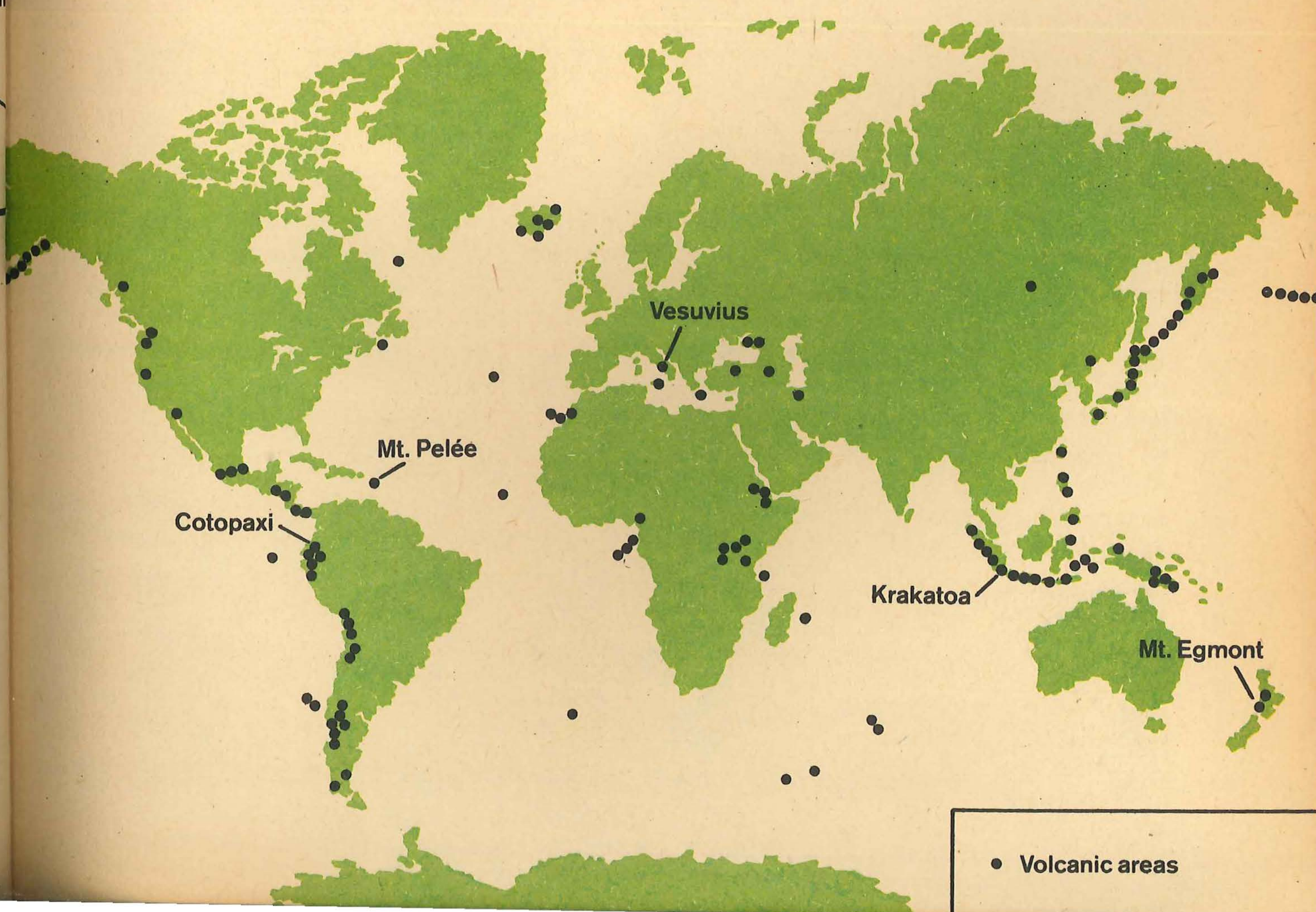
Volcanoes may be extinct which means they have no recorded eruption in historic times (4–5,000 years), dormant which means they have not erupted for many centuries (but within the last 1,000 years), or active.

There are several thousand volcanoes on the surface of the earth. Of these, between 300 and 600 are active. There are two reasons for the large range of possible active volcanoes. The first is due to the fact that it is difficult to decide whether a volcano which has not erupted for several hundred years

Movements of the earth's convection currents cause the movements of the earth's plates.



This map shows the position of the volcanoes throughout the world.



should be counted as dormant or active. The second is caused by the habit of large volcanoes to develop secondary cones, which may ultimately become bigger than the main crater. In the case of a large volcanic mountain, the different craters may be several kilometres apart and therefore are sometimes recorded as two volcanoes.

Where are volcanoes located?

Two-thirds of all volcanoes occur around the edges of the Pacific Ocean in what is called the Fiery Ring. This extends from New Zealand through Indonesia, the Philippines, Japan and Kamchatka, across to the Aleutian Islands, Alaska and down the west coast of America via the Central American republics to Chile.

Other areas with active volcanoes are the West Indies, the Mediterranean, the mid-Atlantic Ridge, the Great Rift Valley in Africa, Antarctica and isolated areas in the Pacific, Atlantic and Indian Oceans. The West Indies contain one of the most famous of all volcanoes, Mt. Pelée, and the Mediterranean includes Vulcano which gave its name to all volcanoes. The mid-Atlantic Ridge includes Iceland which is the most active part of the world. East Africa includes Mount Kilimanjaro, a snow-covered peak within 300 kilometres of the equator. Antarctica contains several volcanic peaks such as Mounts Bird, Terror and Erebus, though the last is the only one with any recent activity.

These volcanoes occur in narrow belts or lines, with only a small number of exceptions such as Hawaiian and Canary Islands. These lines coincide with the edges of the plates which make up the crust of the earth. These large plates of rock bump into each other and cause buckling and weaknesses in the crust which allow volcanic activity to occur. These plates, just like pieces of a jigsaw puzzle, may fit together quite snugly. But, if the pieces of the puzzle are pushed too hard, they will crumple and may break. The plates of the earth's crust push against each other and either crumple or one plate slides under the other.

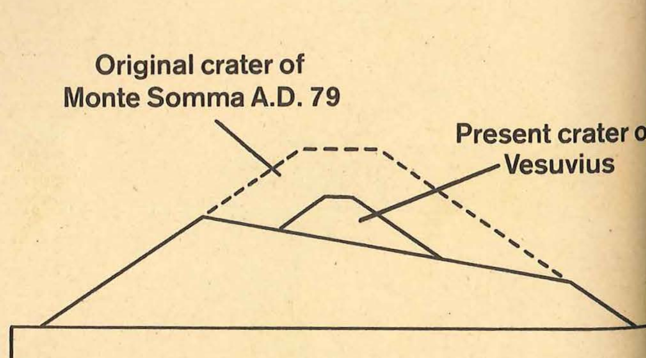
Most volcanoes occur in the Fiery Ring of the Pacific. The areas with the greatest numbers of active volcanoes are: Chile 26, Philippine Islands 12, Java 28, Japan 55, Kurile Islands 39, Kamchatka Peninsula 25, Aleutian Islands 18, Alaska 15, Central America including Mexico 42.

Recent volcanic eruptions have been collected by the Smithsonian Observatory in Cambridge, Massachusetts, and there are records of 87 eruptions in the five years since records began. There were 12 in 1968, 18 in 1969, 22 in 1970, 19 in 1971 and 16 in 1972.

Can a volcano destroy a town?

One of the world's most famous volcanoes is Vesuvius which overlooks the Bay of Naples in southern Italy. It reaches 1,180 metres and has a circumference of 40 kilometres round its

Monte Somme and the present-day cone of Vesuvius.



base. This huge mountain has been built up by successive eruptions which have continued throughout historic times.

In A.D. 79 there was a particularly devastating eruption which destroyed the ancient towns of Pompeii and Herculaneum. White hot ash blown out by the massive explosion fell on Pompeii, and buried the town to a depth of six metres. The ash and outbursts of gas killed all 30,000 inhabitants. Much of the ash has been removed in recent years to expose the old town. The ash is carried away to nearby farms as it creates rich soil. In the ruined city the fossilised remains of a Roman soldier were found still at his sentry post. This shows how sudden and dramatic the arrival of the lethal gas must have been. Many bodies left holes in the ash, and when archaeologists exposed these by digging, the cavities were filled with plaster to recreate the original shapes.

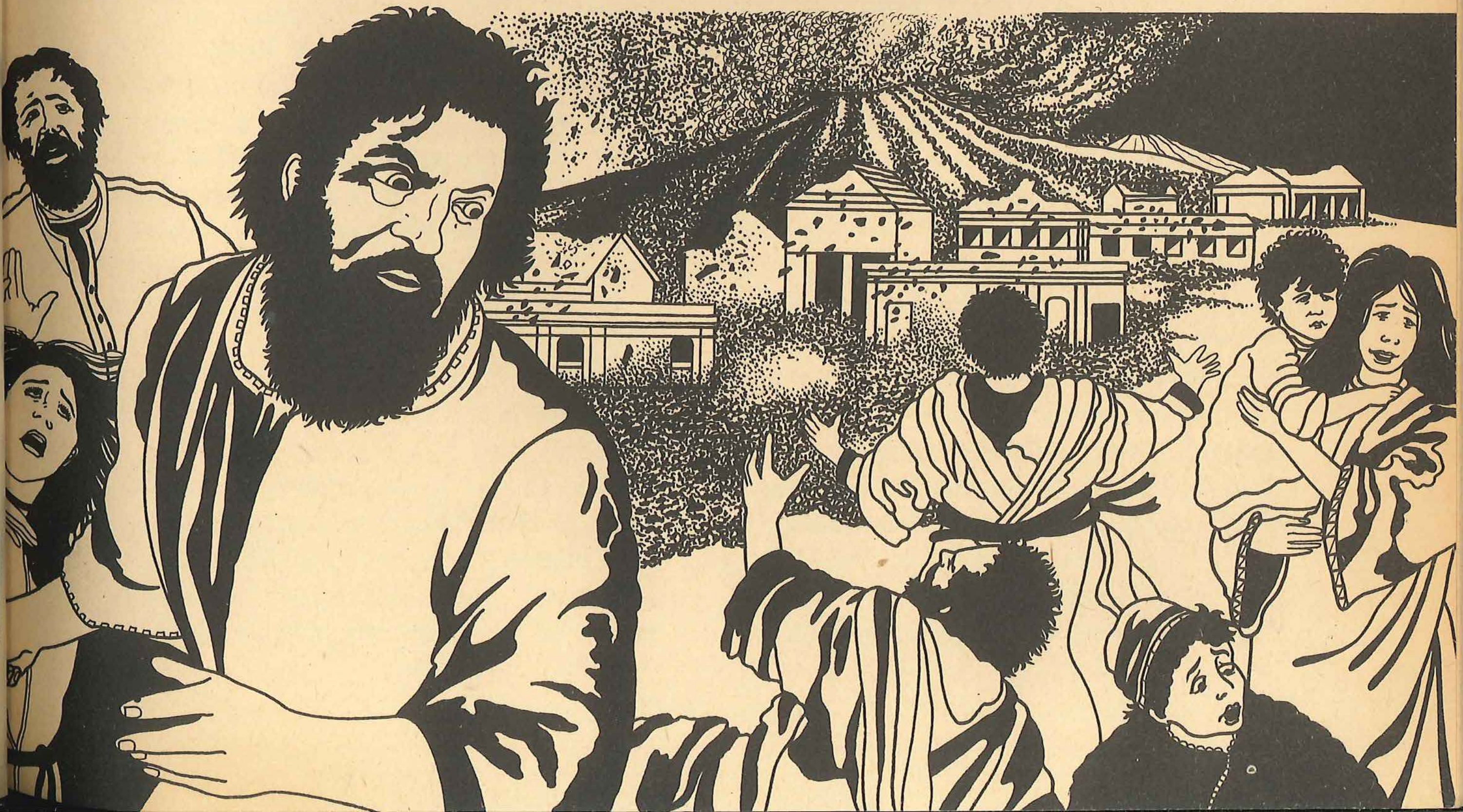
During the same eruption, Herculaneum was covered by streams of hot mud, caused by heavy showers of rain, resulting from the eruption, turning the volcanic ash into rivers of mud. The mud hardened over the ruins of Herculaneum which were not rediscovered until 1738.

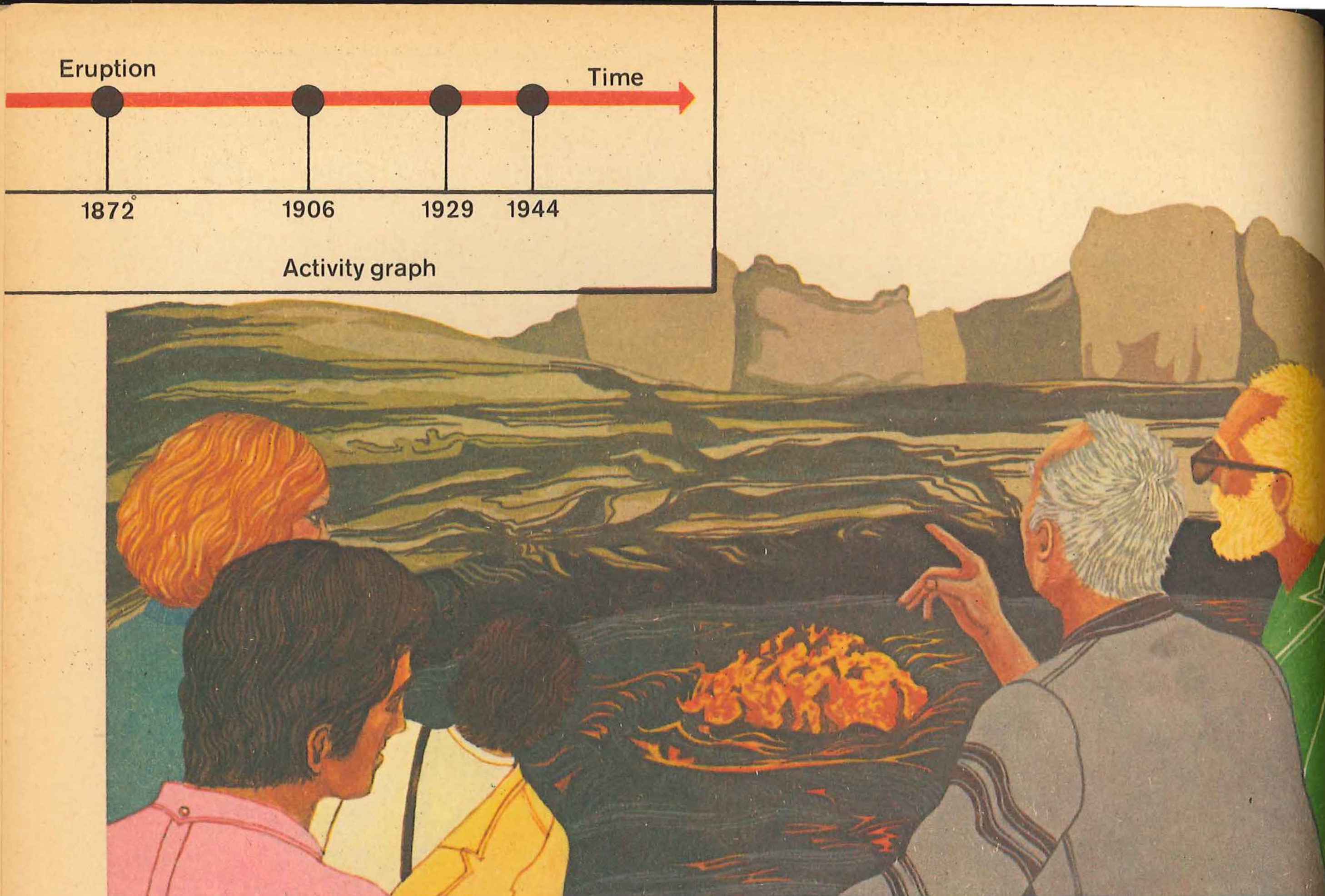
The eruption of A.D. 79 left an enormous crater more than three kilometres in diameter. Before this time the volcano was probably a nice cone shape. The pre-A.D. 79 crater was called Monte Somma and all the recent activity has occurred within this crater. The present cone has a crater about 1.5 kilometres in circumference and is surrounded by the relics of Monte Somma. The crater wall only survives in the north, the southern edge having been blown away in A.D. 79.

After A.D. 79, 1631 was the next major eruption and this killed 18,000 people. Vesuvius has not really ceased to rumble since then and during the last three hundred years there has been activity of the Strombolian and Vulcanian type.

The most recent eruptions have

When Vesuvius erupted in A.D. 79 the town of Pompeii was completely destroyed.





Scientists have studied Vesuvius for many years and have been able to draw up an "activity graph".
As Vesuvius has been "quiet" for many years, tourists are able to go to the top of the crater and look over its edge.

occurred in 1872, 1906, 1929 and 1944. The 1944 activity lasted for 17 days and consisted of a lava flow, some gases and explosions. The 19th and 20th century frequency suggests an eruption every 15–35 years and there has not been one now for 30 years. Instruments placed on the mountain have detected increasing tremors and activity below the surface. Parties of tourists are regularly taken to the edge of the crater in spite of the likelihood of activity in the near future. Perhaps this thought makes a visit to Vesuvius more exciting. Some volcanoes such as Vesuvius or Etna are so large that even a large explosion could leave most of the volcano unaffected. Residents and visitors are not really in any great danger though someone may be unlucky if a big eruption occurred.

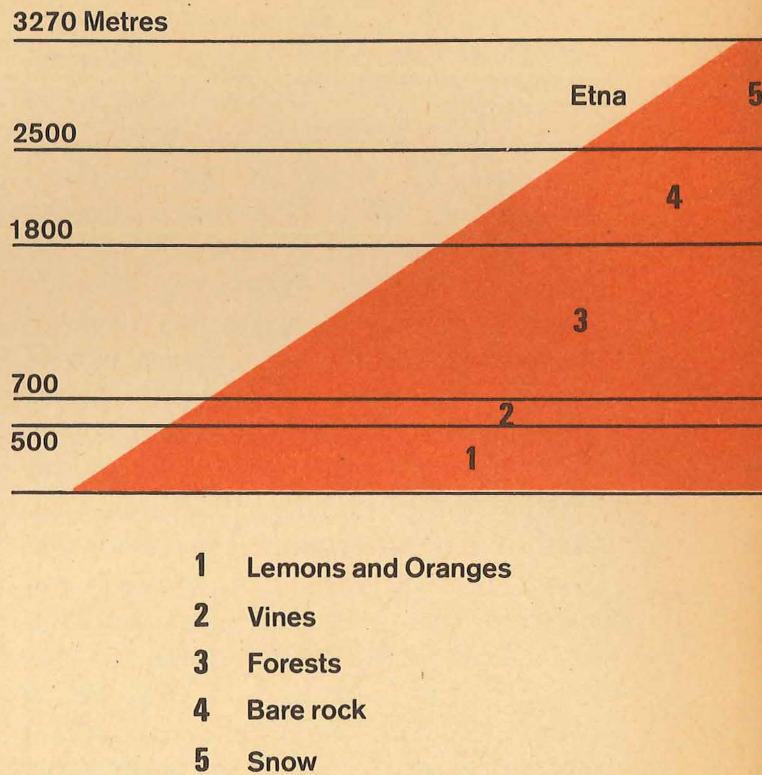
Can people live on active volcanoes?

Etna is situated in the east of Sicily and dominates the scenery of the eastern half of the island. It has been built up by successive eruptions of cinders, ash and lava, in what was formerly a large sea inlet. The mountain now reaches 3,270 metres and has a circumference round its base of 130 kilometres. It covers an area of 1,300 square kilometres, and is populated by at least half a million. There were 17 eruptions in the 18th century, 19 in the 19th century and there have already been 8 in the 20th century.

One of the most devastating periods was in 1669, when lava covered much of Catania and severe earthquakes also shattered the town. One cubic kilometre of lava was erupted in 1669 and it came from Monte Rossi, a subsidiary cone on the slopes of the mountain. There are more than 300 of these subsidiary cones on the slopes.

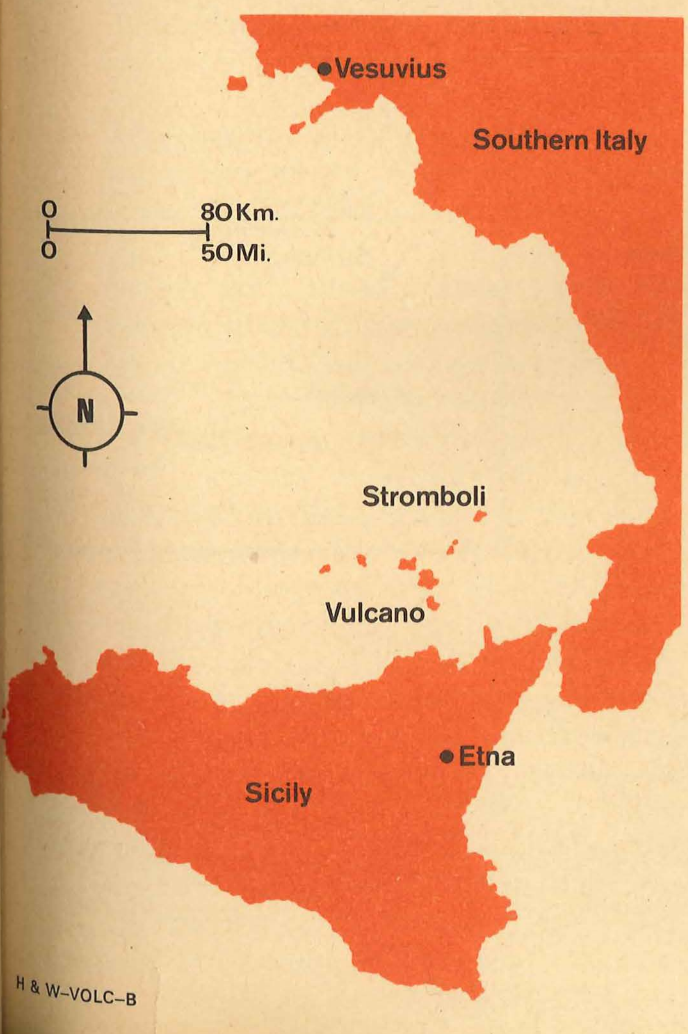
The most recent eruptions occurred in 1971 and 1974. The 1971 lavas are still smoking in places and the main crater at the summit is also smoking continuously.

Because this mountain is so high, there are considerable differences in climate between the Mediterranean coastline and the higher levels of the mountain. The main farming area is below 700 metres. At the lowest levels the farmers grow lemons and oranges in an area where frosts do not occur. Higher up at 500 metres, vines are the main crop as they can survive the lower temperatures which occur in winter. Above the farming zone there are forests which extend to 1,800 metres, and beyond these is a barren zone and then snow. The snow may extend as far down the slopes as 1,500 metres in winter, and has encouraged a skiing industry. It is strange to consider that a smoking volcano is capped by a layer of snow. This is made possible because rock is a poor conductor of heat and therefore the subterranean warmth is not able to melt the snow. Other volcanoes with snow include Mount Erebus in Antarctica which is completely and permanently covered, and there are many volcanoes which have snow on their summits for part of the year, including Kilimanjaro nearly on the equator.



The differing zones of Mount Etna.

The location of the famous Mediterranean volcanoes.



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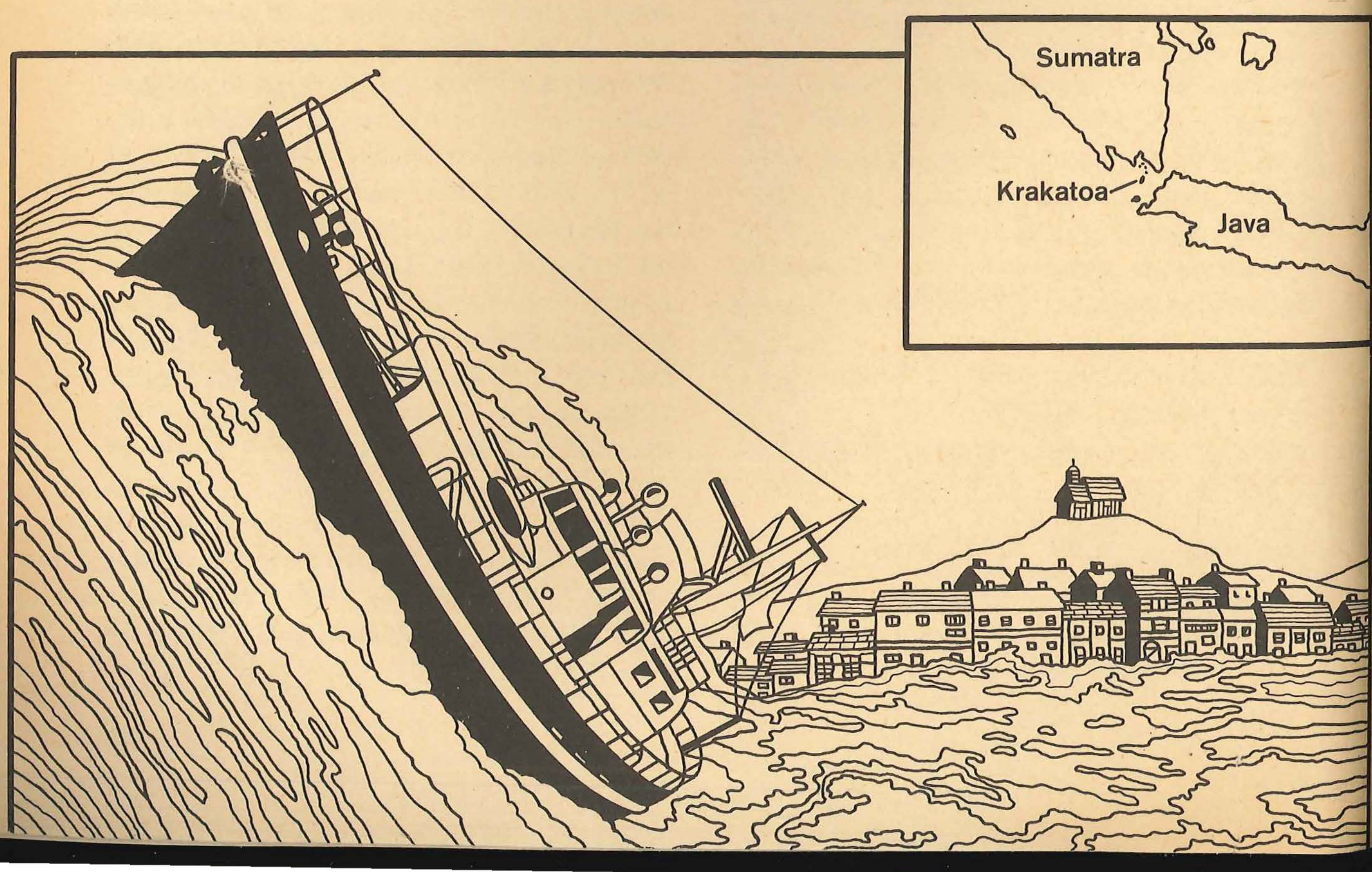
Which was the biggest recorded eruption?

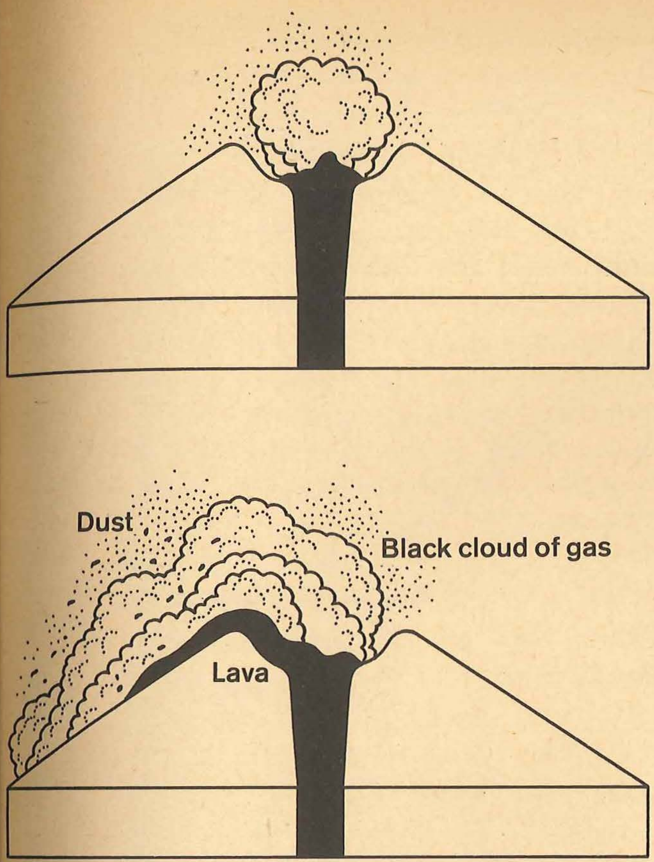
The small island of Krakatoa is situated between the bigger Indonesian islands of Java and Sumatra, and its most famous eruption occurred in 1883. This vast explosion blew away two-thirds of the island, an estimated 18 cubic kilometres of rock. Gases and lava were thrown over 16 kilometres into the air. The ash spread over a total area of 770,000 square kilometres, and caused darkness for 2½ days. Muddy rain fell on Djakarta. Within 15 days the dust had circled the earth and some remained in the atmosphere for two years, causing many red sunsets. The main explosion occurred at 10 a.m. on the 27th August and was heard throughout Java. It was heard over 3,200 kilometres away in central Australia at 2 p.m. The tidal wave exceeded 35 metres in places, and even reached Africa. Krakatoa itself was uninhabited but the effects were disastrous in Java and Sumatra. 295 villages were flooded, 36,000 people were killed, and a Dutch warship was carried nearly 3 kilometres up a valley and dumped 9 metres above sea level.

These tidal waves, called tsunamis in Japan where they are frequent, have no connexion whatsoever with tides. They are caused by submarine earthquakes or volcanic activity which send out waves rather similar to the ripples created by throwing a stone into a pond. The tsunamis travel at 700 k.p.h., but are scarcely visible in the open ocean. When they travel into inlets and river estuaries the effect of the wave is concentrated into a narrow space and becomes much higher, a maximum of 60 metres having been recorded.

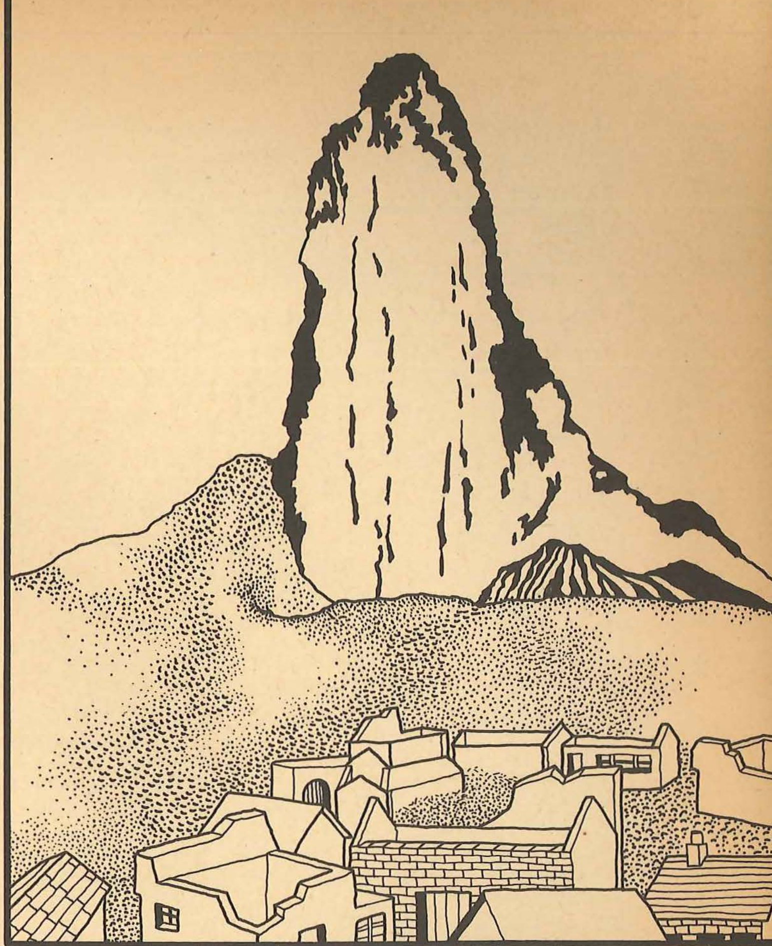
Before 1883, Krakatoa had been dormant for 200 years. Since then there has been mild activity in 1927, 1933, 1953, and 1959. In recent years there have been increased rumblings.

Tidal waves caused by underwater volcanic activity can be very dangerous—especially when they move into narrow inlets.





A nuée ardente emerging from the crater.



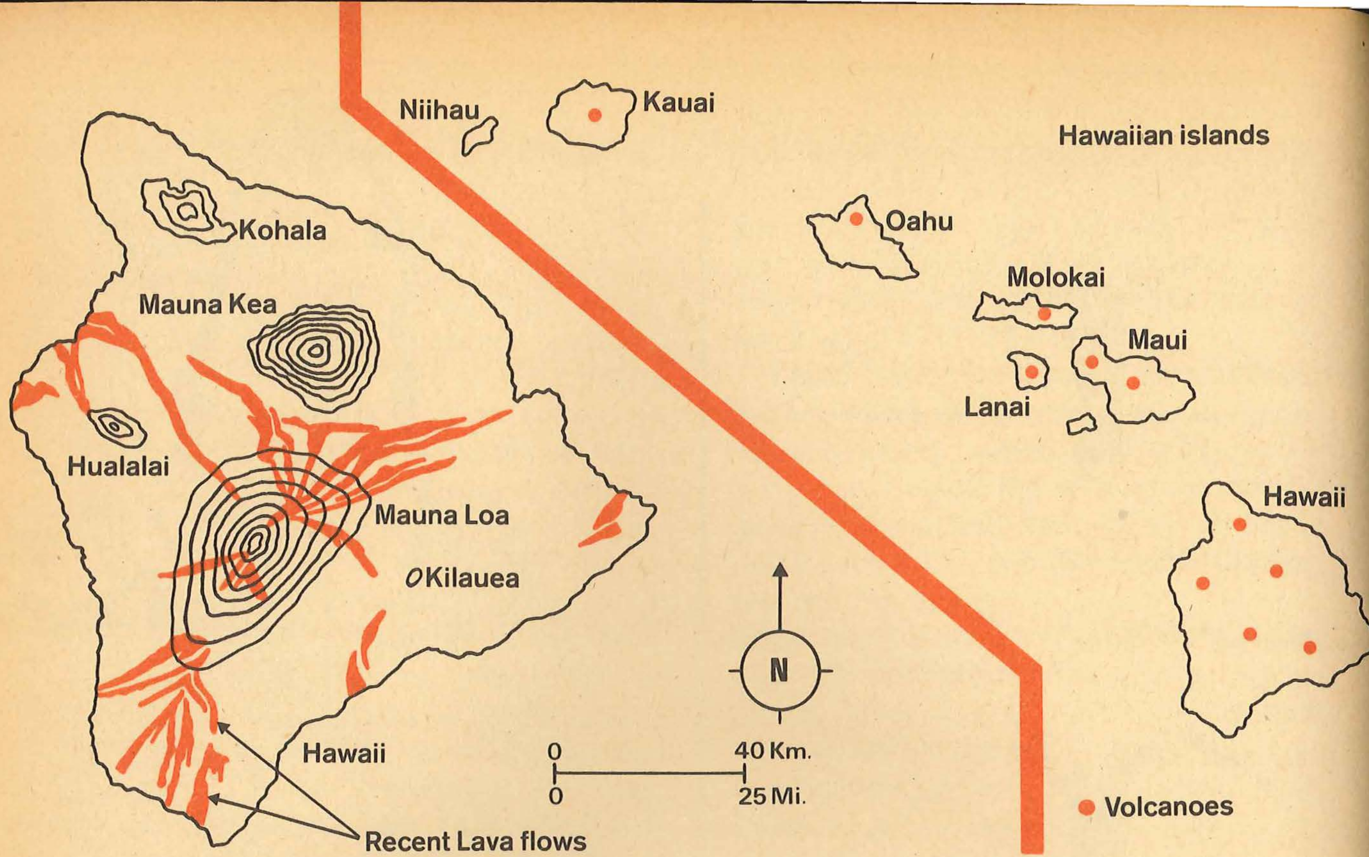
The spine of acidic lava at Mount Pelée.

Can volcanic gases be dangerous?

The Antilles in the West Indies contain some islands which are coralline and others which are volcanic. There are 8 volcanoes in the Lesser Antilles including Soufrière on Guadeloupe and also Mt. Pelée. Mt. Pelée is on the French island of Martinique. It erupted in 1762 and 1851, but the most dramatic eruption occurred in 1902, when the top of the mountain was blown off. The eruption of lava continued into 1903. During a fairly gentle phase, the top of one side of the mountain suddenly opened up, and a fiery black cloud appeared. This black cloud was a nuée ardente, which is a cloud of gas which carries dust particles and small lava fragments. This cloud poured downhill at 320 k.p.h. The gaseous cloud quickly travelled the 8 kilometres to St. Pierre, the capital of the island. The population of St. Pierre was 28,000, all of whom perished, except for a man in prison who was in a dungeon out of reach of the noxious gases, which killed everyone else. The gases were at 700°C and when they reached the harbour they made the sea boil, and so even those people in boats were not safe.

After the eruption, a spine of lava remained protruding from the crater. The lava was a very slow flowing acidic type which cooled and solidified quickly. This enabled the spine to form and it actually reached a height of 280 metres above the mountain top. It did not survive very long, as erosion removed it within a few months.

Mont Pelée showed signs of activity again in 1929 and 1932.



Volcanic activity among the Hawaiian Islands.

Are all volcanoes located on the edges of the earth's plates?

The Hawaiian Islands are the 50th state of U.S.A. and are located in mid Pacific. They are all of volcanic origin and have grown up from the ocean floor. They formed in a sequence, with a new island appearing every million years approximately. The oldest islands are in the west and the youngest and most active is Hawaii at the eastern end.

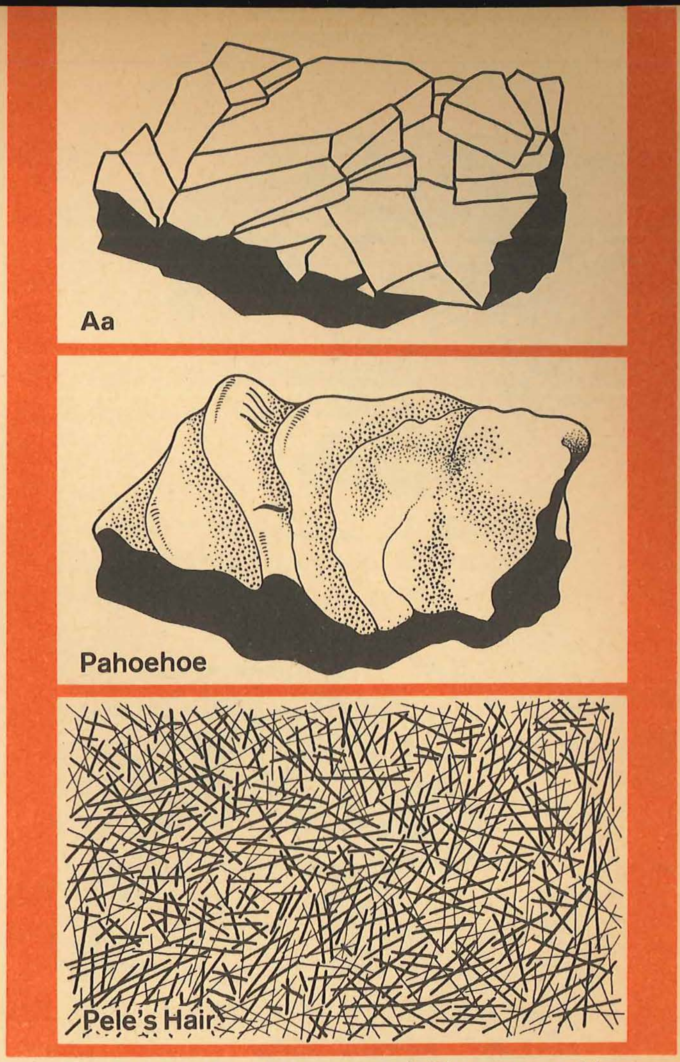
The Hawaiian Islands are not on the edge of one of the plates which make up the earth's crust. They lie over one of the hot spots which are situated just below the surface in a small number of localities. The Hawaiian hot spot has not moved, but the overlying crust has changed position because of the movement of the Pacific plate. So, after a dormant period of a million years, the next spell of activity would form a new volcano which would erupt, intermittently, for a few thousand years. At present, the hot spot is still below Hawaii and the activity is in Kilauea. The hot spot is like a bunsen burner with a slow moving conveyor belt moving over the top of it. Every so often, a few thousand or even a million years, the bunsen or hot spot burns a hole through to form an eruption.

What is a shield volcano?

The greatest volcano of the Hawaiian group is Mauna Loa which rises to a height of 9,140 metres, of which 4,270 metres are above sea level. Its base has a diameter of 110 kilometres. The main crater of Mauna Loa is 8 kilometres in circumference and the walls are over 300 metres deep. This massive mountain is called a shield volcano because it is similar in shape to an upturned shield. All the basic lava type of volcanoes are now referred to by this name. There are examples in New Zealand and elsewhere, and the recent eruption in the Westmann Islands was of the type suitable for creating a shield volcano.

There are subsidiary craters on the slopes of Mauna Loa which are still active and one of these, Kilauea, has a good example of a caldera. The caldera was caused by lava which was underground all draining away sideways through another outlet. Rock collapsed into the hollow which had been created, and the resulting caldera has a diameter of 3 kilometres and a depth of 150 metres. Kilauea is quite accessible and has been studied since 1823, with very detailed observations since 1950. A small crater within Kilauea caldera is called Halemaumau, and this contains bubbling lava which rises and falls and sometimes overflows. In 1959 there was an eruption from the side of the caldera and the fountain of lava reached 600 metres in height. In 1960 the Halemaumau crater collapsed presumably into the gap left by the removal of magma.

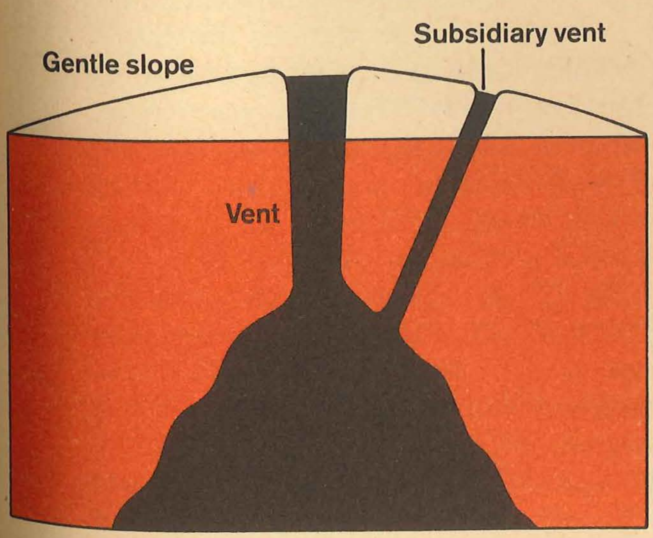
Volcanoes are very much in evidence in the Hawaiian Islands, and some Hawaiian words have been introduced into the terminology of vulcanism.

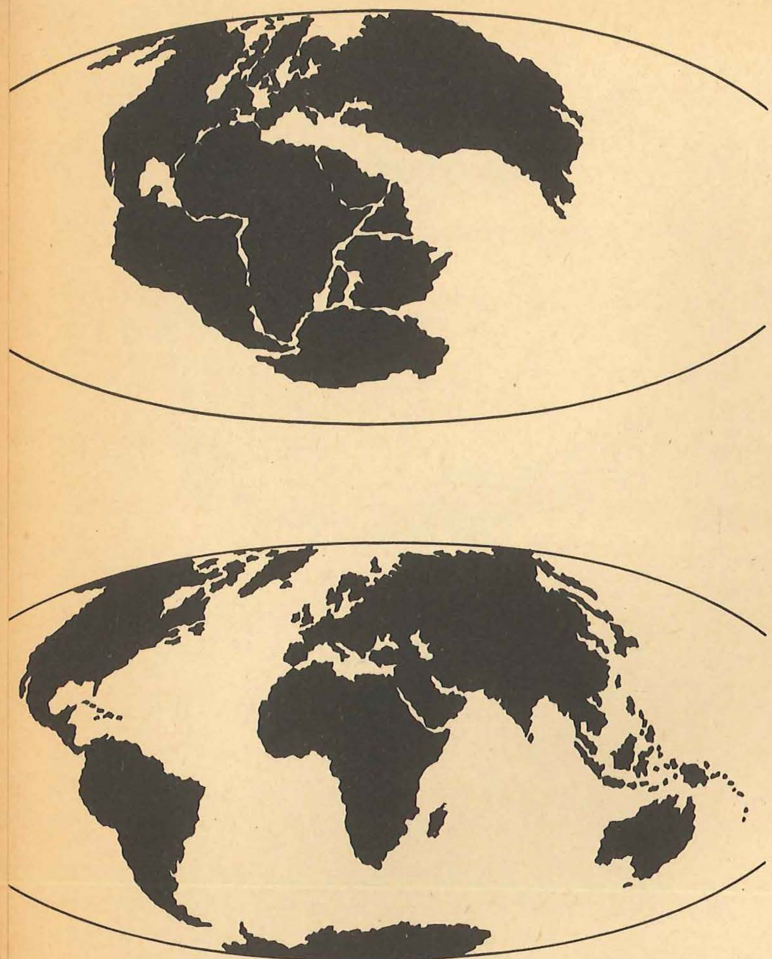


The diagrams show the structure of different types of lava.

Lavas are either aa (pronounced ah ah) or pahoehoe. Aa lava has a block-like structure with a rough clinkery surface. Molten lava continues to flow beneath the surface after the top has ceased to move. This stretches the top and makes it rough and jagged. Gases within the lava escape violently and help to cause the rough blocky structure. Pahoehoe is much smoother and has a ropey structure. The gases in this type escape quietly. Another rather nice Hawaiian term is Pele's hair. Pele was the Goddess of Fire and her name has been given to thin hair-like strands of glassy basaltic lava which have been stretched and blown out by the wind. The strands generally originate where gas bubbles within the lava have burst.

A shield volcano.





The position of the earth's continents has altered since the Mesozoic era due to the line of volcanic activity down the middle of the Atlantic Ocean.

Why does the middle of the Atlantic contain volcanoes?

There is a line of volcanic activity running down the middle of the Atlantic Ocean from Iceland through the Azores and Ascension to Tristan da Cunha. This is the line along which the bed of the Atlantic Ocean is splitting, and the Americas and Europe are drifting apart. Most of the drift has taken place since the beginning of the Eocene period between 50 and 60 million years ago. A long time ago, in the Secondary or Mesozoic era, Europe and Africa in the east were very close to America. This can be seen clearly by the way in which north-east Brazil would fit into the Gulf of Guinea in West Africa. The upwelling of new lavas from the middle of the Atlantic has not only caused much volcanic activity but has also formed a line of hills called the mid-Atlantic ridge. Most of the Atlantic volcanoes are near this ridge but there are also isolated volcanoes in the Canaries. These are caused by hot spots of magma approaching close to the earth's crust, similar to those in the Hawaiian Islands.

The Canary group contains 7 major islands all of which are volcanic. The highest peak is in Tenerife where the massive Mount Teide reaches 3,710 metres. This volcano has not been active for 200 years, although its crater still emits sulphurous fumes in a few

The evacuation of Tristan da Cunha.

places. The peak is situated within an enormous caldera called Las Canadas which has a diameter of 9 kilometres and a circumference of 70 kilometres. The latest activity in Tenerife was a small eruption near Chinyoro in 1909, but the most recent activity in the Canaries was on the island of La Palma. This erupted in 1949 and again in December 1971 when activity continued for about four weeks.

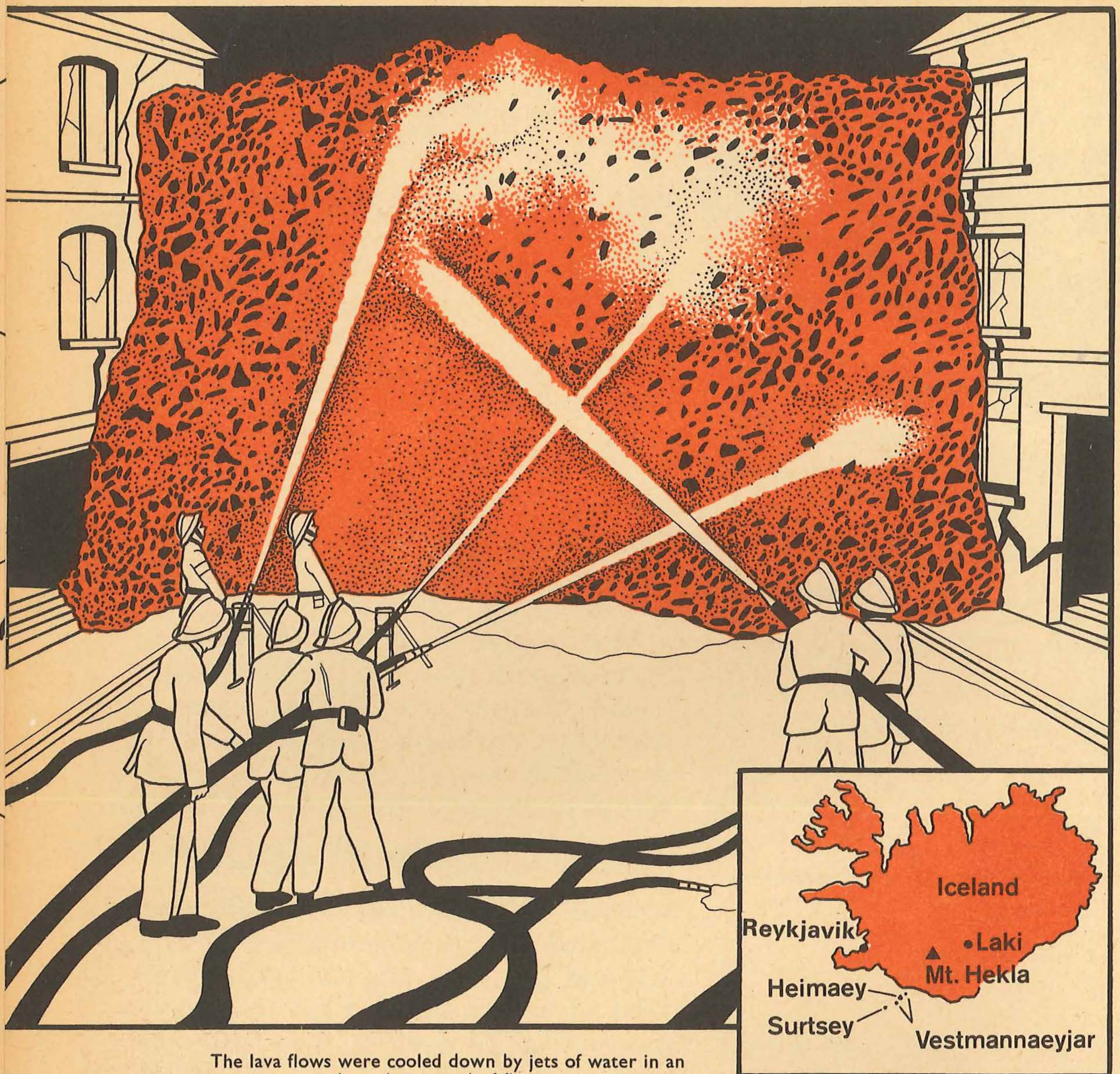
Along the line of the mid-Atlantic ridge there was activity in the south in 1961, when Tristan da Cunha erupted and the island was temporarily evacuated, with all the inhabitants settling in England. Most returned to Tristan in 1963.

Which is the most active part of the world?

At the other end of the ridge is Iceland which is the most active volcanic region in the world. There have been recent eruptions from both true volcanoes and also fissures. Laki had a famous fissure eruption in 1783 and Mount Hekla erupted from its cone in 1947. During this 1947 eruption, some ash landed on southern Europe. In 1783, Laki had 6 months of eruptions from 32 kilometres of fissures. This represented the world's greatest basalt eruption in recent centuries. 12 cubic kilometres of lava covered an area of 560 square kilometres.

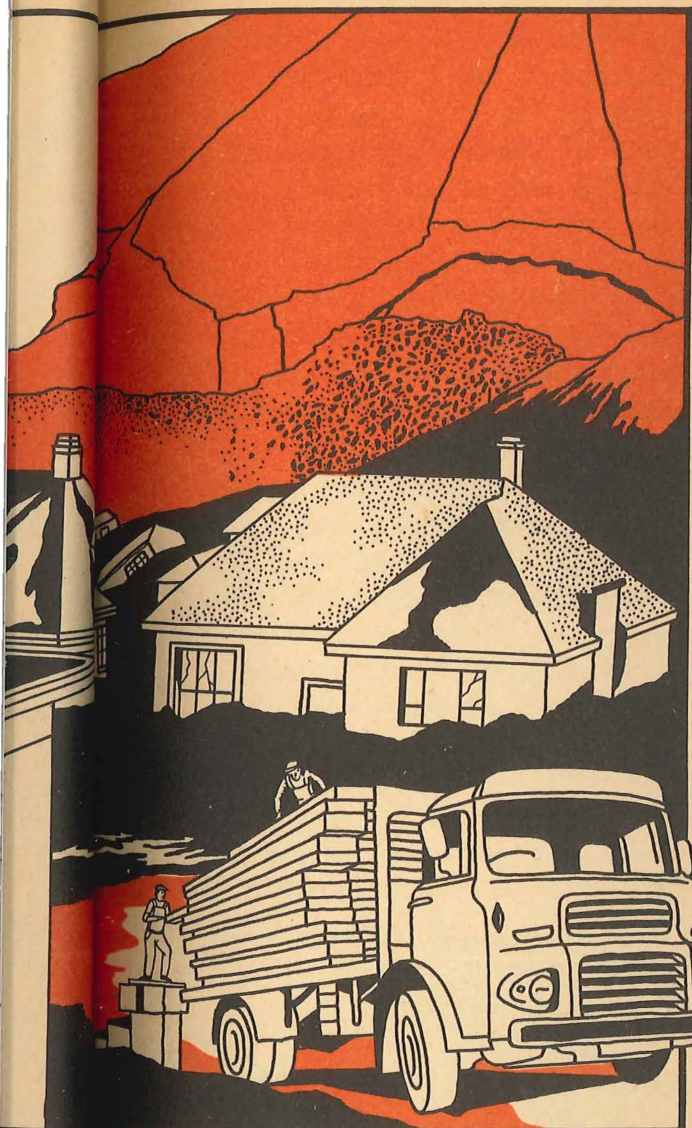
More recent has been the activity at Surtsey and Heimaey in the Westmann Islands. Surtsey is a small new island which was created in November 1963. A volcanic eruption from the sea bed was first reported by fishermen who noticed the sea was boiling. Within hours a column of ash and gases reached 15,000 metres, and ash was deposited on Vestmannaeyjar. Only ash and gas were erupted until April 1964 when lava bubbled out to ensure the survival of Surtsey. This was the birth of the Hawaiian type of shield volcano which had never been witnessed elsewhere. It reached a height of 170 metres above sea level and will now survive as a result of the solid core of lava. This contrasts with a small island called Little Surtsey which was formed by eruptions in 1965. This consisted only of ash, and the sea was able to demolish this as quickly as it was being built up above sea level.

The creation of Surtsey caused no serious problems and was greeted with pleasure by botanists and ecologists who have been able to study the ways in which plants and animals settle on newly formed land. In contrast to



The lava flows were cooled down by jets of water in an attempt to reduce their speed of flow.

Surtsey was the destruction and expense caused by Helgafell on Heimaey. Heimaey was the most important of the Westmann Islands, and its main town Vestmannaeyjar was responsible for 15 per cent of the fishing catch of Iceland. The eruption started in January 1973 after 6,000 years of inactivity and, by early February, 200 million tons of tephra (cinders and ash) had been ejected. Lava flows moved into the town and one of them partially blocked the harbour, which was the basis of the island's existence. The cinders blown into the air frequently reached 9,000 metres in height. Masses of ash fell on the town and buried many of the houses. Most of the inhabitants moved to Reykjavik and it was feared that their town would be completely destroyed. Fortunately the eruption ceased in June 1973, since when many of the inhabitants have returned to repair their houses. Compensation is being paid for the houses and businesses which have been destroyed. Grass seed sown over the ash has started to grow, and many tourists are visiting the area so the restoration of normal economic life is taking place.



Clearing up the mess!

Can volcanic dust create problems?

South and Central America contain many relics of vulcanism. In South America there are vast expanses of lava from fissure eruptions in the Brazilian Plateau, and in the Andes there is much lava and ash and many cone shaped peaks. All the highest summits of the Andes are volcanic and include Chimborazo, 6,570 metres, and Cotopaxi. Many of these are now extinct, but there has been recent activity in Cotopaxi, 6,200 metres, the highest active volcano in the world, and also in Chile where volcanoes, earthquakes and tsunamis caused destruction in 1960. Ecuador and Peru both have volcanoes above the snow line, and when these erupt they will melt the snow and cause mud rivers to flow rapidly down valleys and destroy everything en route.

Mexico contains 12 volcanoes, and the republics between Mexico and Colombia another 30. These small republics are really a collection of volcanoes which have joined up to link North and South America. Many of the peaks are still active, including Izalco in Salvador, which is called the Lighthouse of the Pacific because of its continuous flames. One of the most depressing examples of recent activity has been in Costa Rica, where San José, the capital, received a daily coating of ash from Irazu, a volcano which overlooks the town. In March 1963,

The Lighthouse of the Pacific.

Irazu began to erupt for the first time for 1,000 years. There was no lava but several daily eruptions of ash which frequently blew up to a height of 9,000 metres. Streets had to be swept every few hours, all machinery was clogged by dust, and roofs needed to be swept before the weight of ash led to their collapse. In future centuries this ash may become rich farming soil similar to that found nearby and in many other parts of Central America, where the isolated areas of good farming are all located on volcanic soil. At present, however, the ash is purely destructive and it will take many decades or even centuries before new ash can be turned into productive farm land.

These Central American volcanoes are part of a series which extend the full length of the Americas. They are part of the Fiery Ring of the Pacific which continues from Alaska across to Kamchatka, and southwards through Japan as far south as New Zealand.

Is New Zealand highly active?

New Zealand is a land of dramatic scenic contrasts, from high mountains with snowfields and glaciers in South Island, to hot springs and active volcanoes in North Island.

South Island has evidence of former volcanic activity such as the old crater which has been flooded to form Lyttelton harbour. Present activity only occurs in North Island where there is a wide range of volcanic effects. Large amounts of basic lava came from fissures in North Auckland. The Central Plateau of North Island was built up by late Tertiary activity, and near Lake Taupo there is a layer of pumice and ash which covers 20,000 square kilometres as a result of 21 cubic kilometres of ash coming from one explosion.

Mount Egmont, 2,510 metres, is a conical dormant volcano, but there are active volcanoes, Ngaurohoe, Tongariro and Ruapehu, in addition to the geysers and hot springs. White Island in the Bay of Plenty is the top of a submarine volcano which has been active since first being seen by Captain Cook in 1769.

The geysers and springs, and the mud volcanoes which are similar to large pans of bubbling treacle or porridge, are all found in the same area. The Maoris have used them for centuries both for washing clothes and for cooking. They cooked their food in hot springs by putting the food into bags and lowering them in the water.

The hot subterranean rock, which is possibly molten, heats water to 250°C. This feeds many springs and geysers. It can also be tapped by sinking bore holes down to the heated level. There is enough geothermal power to double New Zealand's electricity production if necessary.

The Maoris have always made good use of the hot springs.

The Creative Effects of Volcanoes

Why are some volcanoes famous?

Volcanoes are famous for their dramatic and sometimes disastrous effects, which may involve the loss of life or damage and disruption to property and farmland. However, most volcanic activity is on a small scale and does not affect too many lives. Even enormous explosions such as Krakatoa create land on a small scale when compared with the effects of folding which can create whole ranges of mountains such as the Himalayas.

The most famous volcanoes are:

i. those which are frequently active in areas with many inhabitants, e.g. Etna;
ii. those which explode violently in a dramatic fashion, e.g. Krakatoa;
iii. those which devastate towns, e.g. Mont Pelée or Vesuvius;
iv. those in the more advanced parts of the world, e.g. Icelandic eruptions receive more publicity than those in Central America.

What are the most dramatic effects?

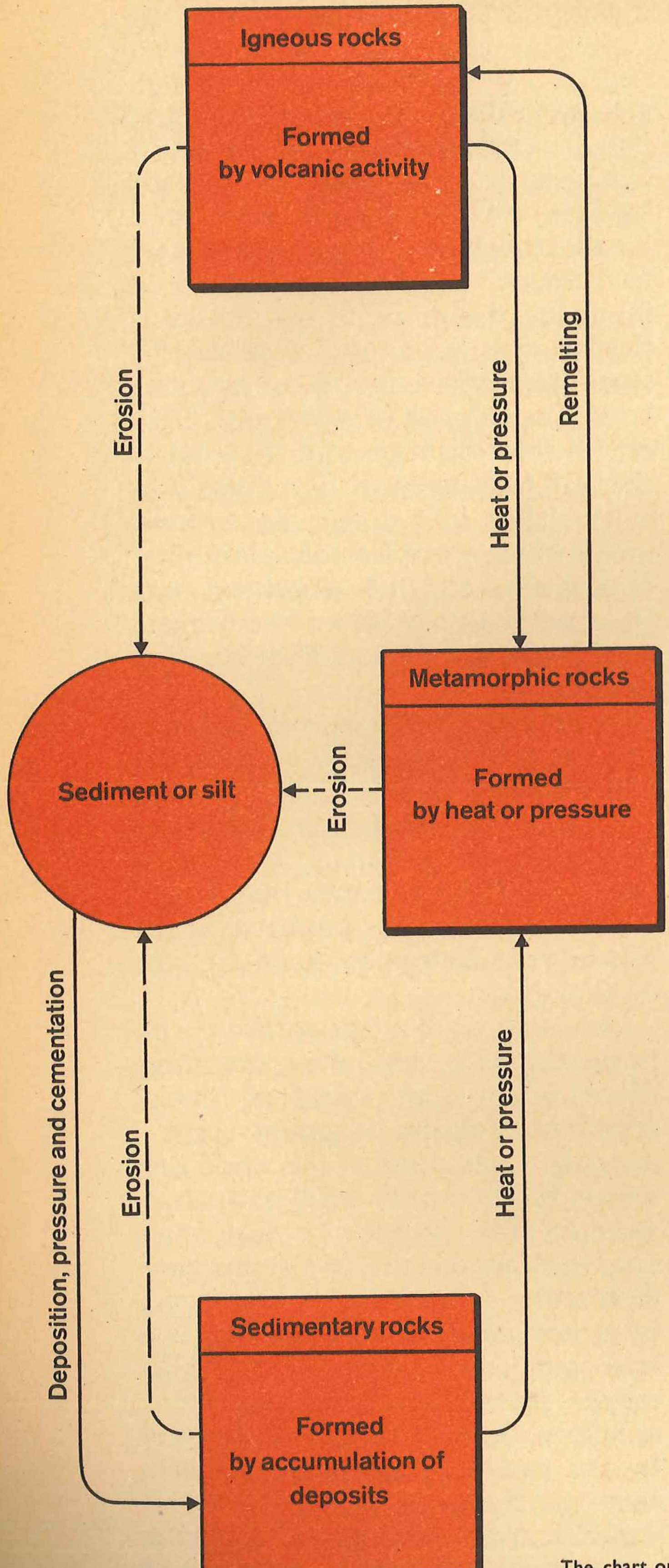
The dramatic effects may take different forms, such as lava flows overwhelming towns; explosions blowing out millions of tons of rock; cinders and ashes burying towns; nuées ardentes or tsunamis. A lava flow was responsible for the disappearance of several villages on the Canary Island of Lanzarote, during eruptions from Mt. Timanfaya which continued from 1730 to 1736. Lava flows have also buried many villages on the slopes of Etna.

Large explosions have been particularly dramatic in the Vesuvius eruption which created Monte Somma and also in Krakatoa in 1883. The eruptive power of volcanoes was well shown by Cotopaxi in 1929, when a 200 ton boulder was hurled 14 kilometres. Small explosions may create rather picturesque activity, similar to a fountain of fire in a big fireworks display. This was true of Etna in 1971. Rock fragments and blobs of lava may be thrown up out of the crater. They drift a short distance with the wind as they fall back to earth. The liquid lava will solidify into rough pear-shaped lumps which are called volcanic bombs. The cinders and ash associated with Vesuvius in A.D. 79 buried Pompeii and cinders also buried homes on Heimaey in 1973.

Nuées ardentes are unusual and rare, and the most dramatic was that which affected Mont Pelée in 1903.

Tsunamis are much more frequent as they occur with earthquakes as well as volcanoes. They are mostly rather small and affect few people, but occasionally will be very destructive, as in the case of Krakatoa.

The famous volcanoes are those with large, dramatic and often disastrous effects, but these are not typical of most eruptions. Volcanic eruptions are frequent in many parts of the world and mostly they are quite small and inconvenience few people. In fact most eruptions are constructive rather than destructive as they build new mountains and create new land. This new land may cover many square kilometres in the case of some fissure eruptions, or build up large mountains. In the case of large volcanic peaks such as Etna, or Mount Teide in Tenerife, over 3,200 and 3,700 metres respectively, numerous eruptions have been involved in their construction.



How are rocks formed?

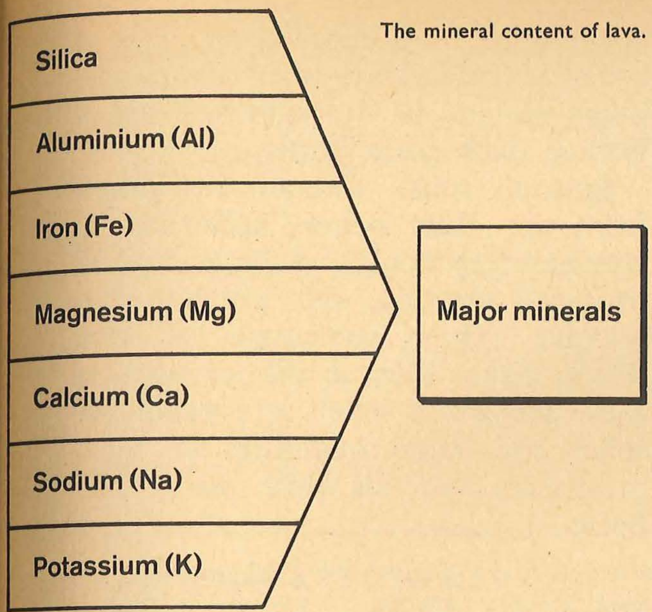
The most constructive aspect of volcanoes is in the formation of new rocks. It has been estimated that 3 cubic kilometres of new material are created annually. This is fast enough to form the entire earth's crust in 4,500,000,000 years, which is the estimated age of the earth. When rocks are created they are in liquid form, and provide proof of the great heat below the surface.

Rocks which originate from volcanic activity are called igneous rocks and represent one of the three groups of rocks. The other groups of rocks are called sedimentary and metamorphic. Sedimentary rocks include sandstones and clays, and consist of sediment or silt eroded from mountains then carried downhill by rivers to be dumped on the sea bed. These deposits accumulate to considerable thicknesses and will eventually be folded to form mountains. Metamorphic rocks are those which have been changed by heat or pressure. They were originally sedimentary or igneous rocks before the metamorphism affected them. Heat from volcanoes or pressure from earth movements could cause the change. As a result of metamorphism, limestone becomes marble and clay becomes slate.

Igneous rocks can usually be recognised by their appearance and different types can be distinguished by their mineral content. Because of their mode of origin, they contain no fossils.

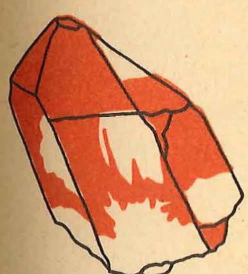
Magma which forms the lava contains many different minerals which solidify as the lava cools. The differing mineral content will determine the rock type which forms. The major component is silica, which accounts for

The chart on the left shows how sedimentary, igneous, and metamorphic rocks are formed.

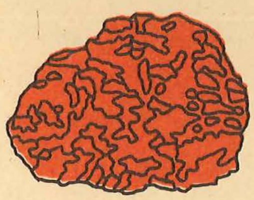


The mineral content of lava.

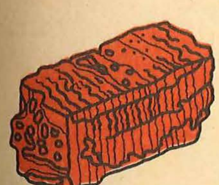
Some of the minerals found in lava.



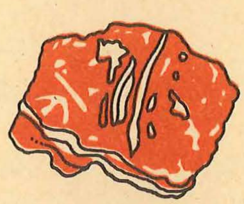
Smoky Quartz



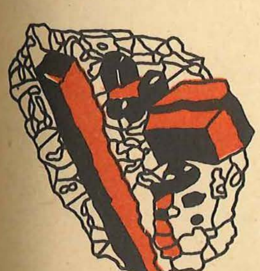
Rose Quartz



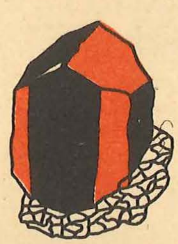
Microcline (Feldspar)



Muscovite (Mica)



Hornblende



Augite

35–75 per cent of total volume. Also there are varying proportions of aluminium (Al), iron (Fe), magnesium (Mg), calcium (Ca), sodium (Na) and potassium (K). These all combine to form the major minerals which occur in igneous rocks, quartz, felspar, mica, hornblende or augite.

When lavas merge from beneath the surface they are very hot, averaging 1,000 or 1,100°C. Once exposed the lava cools steadily until it eventually solidifies and usually becomes too stiff for further movement when the temperature falls below 700°. Lava has occasionally been recorded to move up to 60 k.p.h. on steep slopes, but speeds of more than 16 k.p.h. are extremely unusual even for the most fluid basic basalts. Acidic lavas are always stiff and very slow flowing.

Vast quantities of rock are created by igneous activity. For example, 12 cubic kilometres of lava appeared from Laki in 1783. The Deccan Plateau contains at least 700,000 cubic kilometres of lava from the Eocene age. Even the small Antrim Plateau in Northern Ireland has 800 cubic kilometres of lava.

What are the different types of igneous rocks?

Lavas which reach the surface form extrusive rocks whereas those which solidify underground are called intrusive. Intrusive rocks are also called Plutonic, being named after Pluto, the God of the Underworld.

Intrusive rocks are affected by the heat of the rocks which surround them and cool quite slowly. As they cool, some mineral crystals solidify. The tiny specks of minerals have time to emerge with other specks of the same mineral and so large crystals form. This is the outstanding characteristic of intrusive rocks. They always contain crystals which are visible to the naked eye and may contain crystals of over a centimetre in diameter. If the mineral content contains a high proportion of silica and is therefore acidic, a rock which is light in colour will be formed. Granite is the best example of this and occurs on Dartmoor and several other localities in Britain. Although formed underground, granite can be found on the surface today because all the overlying rocks have been eroded. The Dartmoor granite solidified 280 million years ago and so there has been ample time for the erosion of the rocks which used to cover the granite.

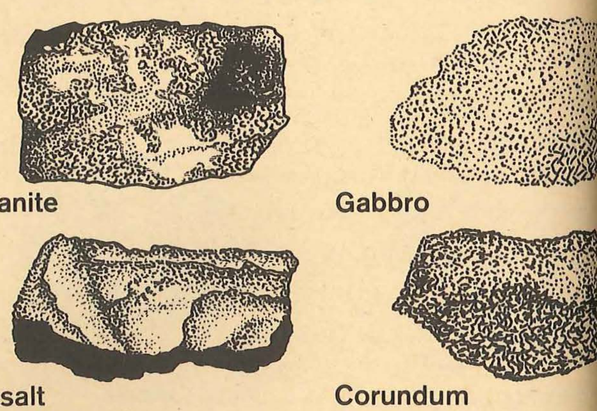
If the deep intrusive rocks are basic, containing little silica, dark coloured rocks are formed. Gabbro is the best example of this, and is found in the island of Skye.

Extrusive rocks are formed by lava which reaches the surface in liquid form. On exposure to the air, the lava cools and solidifies quickly. As a result of rapid cooling, minerals solidify in very small fragments, and the crystals cannot normally be seen by the naked eye. Those extrusive rocks may also be light or dark in colour, according to their mineral content. The commonest is basalt which is very basic and therefore dark in colour. This occurs in Antrim, Giant's Causeway, the Island of Staffa and elsewhere. When basalt cools and solidifies, it often cracks in the same way as wet mud. Hexagonal columns of basalt often result from this cooling. They are to be seen on Giant's Causeway in Northern Ireland and at Fingal's Cave on Staffa. Mendelssohn was so inspired and impressed by the coastal scenery near Fingal's cave that he gave this name to one of his overtures. If lava cools very quickly, for instance if it flows onto frozen rock, or if the eruption is on the bed of a cold ocean, a glass-like rock is produced. This is called volcanic glass or obsidian, and looks similar to a fragment from a broken dark green bottle.

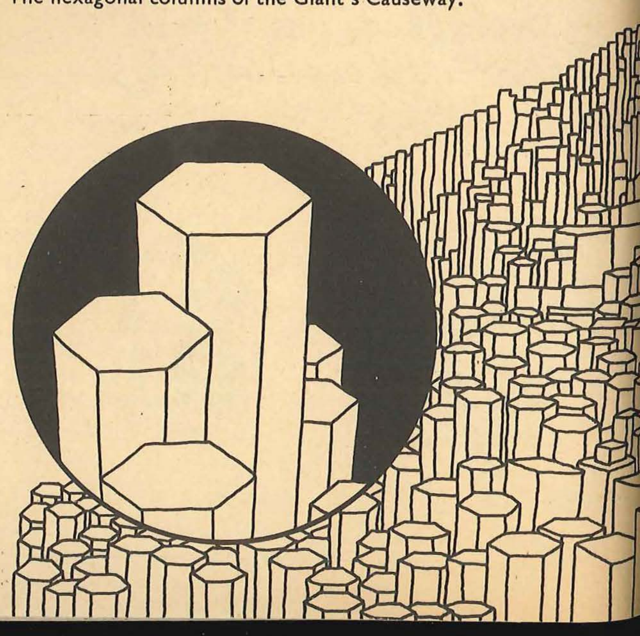
Igneous rocks can be recognised from the chart below, according to whether they consist of large crystals or small crystals, and whether they contain a high percentage of silica which makes them acidic, or whether they contain a small proportion of silica and large quantities of ferro magnesian minerals which make them basic.

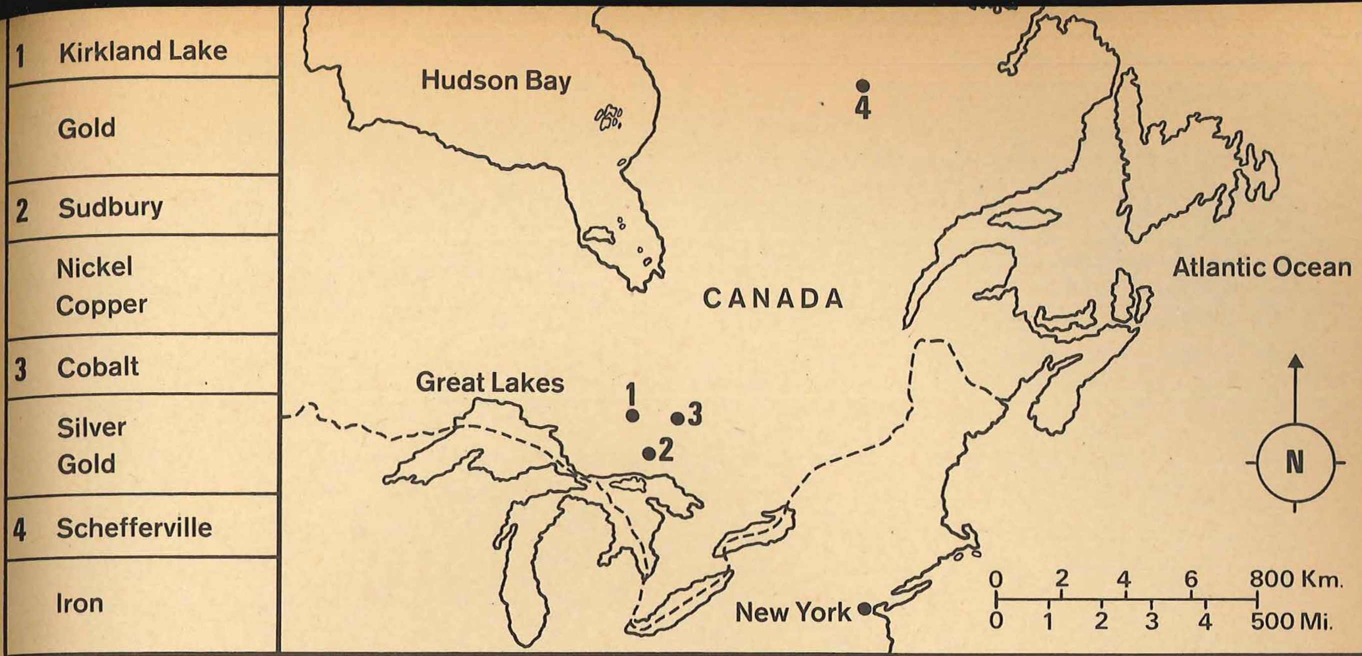
	Acidic	*Intermediate*	*Basic*
small crystals	Rhyolite	Andesite	Basalt
medium crystals	Microgranite	Microdiorite	Dolerite
large crystals	Granite	Diorite	Gabbro

Some igneous rocks.



The hexagonal columns of the Giant's Causeway.





The Canadian Shield which was affected by volcanic activity a thousand million years ago is now a very rich mineral area.

Can precious stones be obtained from volcanoes?

When the earth's crustal plates move apart, they enable hot rock to reach the surface and also, when plates move together, they cause heat and pressure. In both cases, heat and pressure are associated with volcanic activity, with the formation of igneous rocks and also with the formation of many minerals. Most minerals of economic importance, and most precious and semi-precious stones, are associated with this igneous heat. The only major exceptions are oil and coal which are both sedimentary deposits.

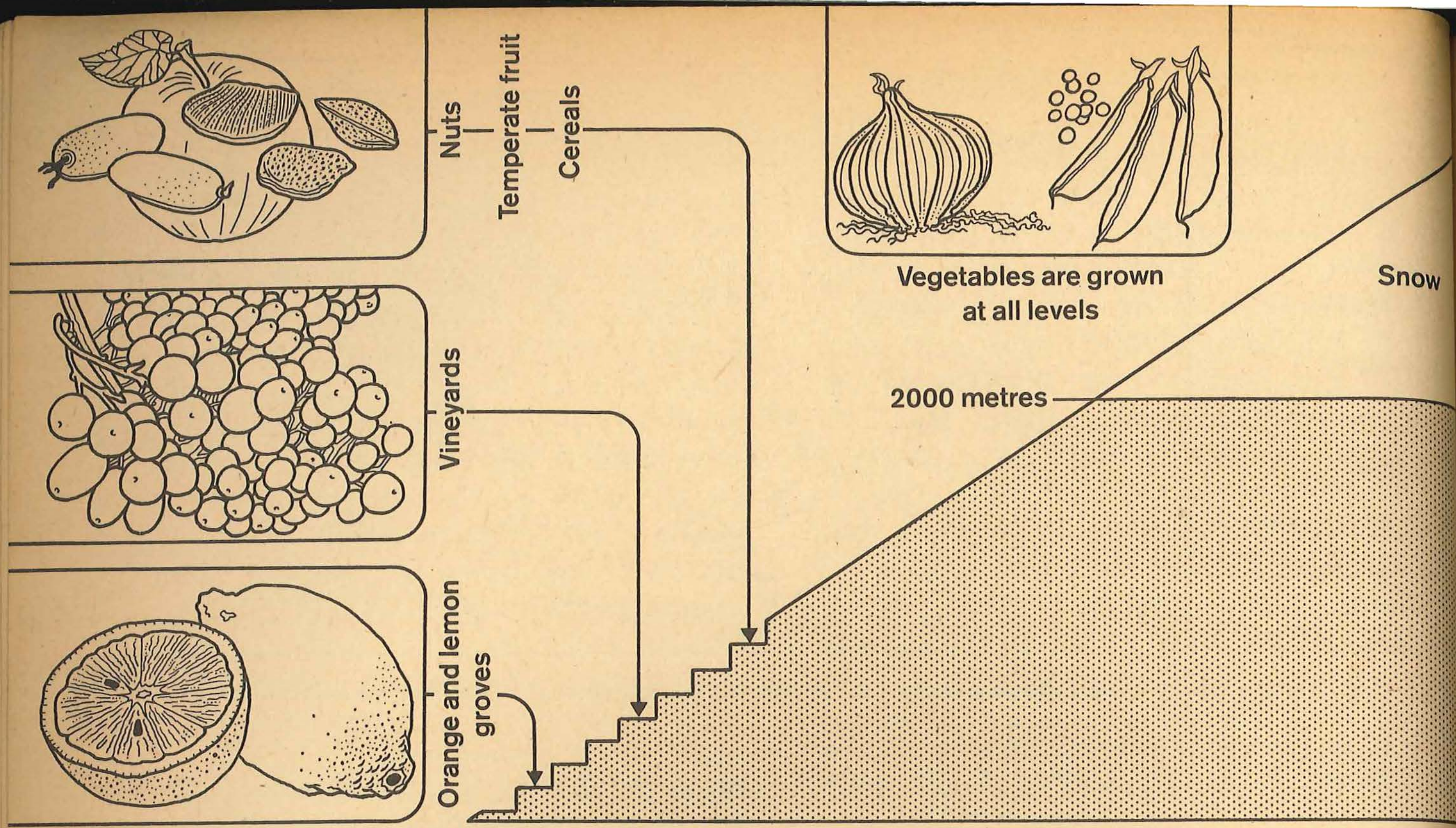
Many minerals which occur in the liquid magma will solidify into precious stones. Also, heated gases from the magma may pass through other rocks and create the necessary changes to form veins or seams of minerals such as tin. Heated liquids may have the same effect.

Gold and diamonds are both formed in association with volcanic rocks, though they may also be found in sedimentary rocks resulting from the erosion of igneous rocks.

Corundum is also often associated with igneous rocks, but it may be connected to metamorphosed limestone (though the metamorphism may be due to heat from igneous activity). There are many useful or precious varieties of corundum such as sapphire, ruby, amethyst, emerald, all of which differ because of slight variations in chemical content.

Sulphur is another useful mineral associated with vulcanism. It is formed in volcanic craters due to emission from underground, and is also found near some hot springs such as those in Yellowstone National Park.

Some of the richest mineral areas in the world are those associated with very ancient volcanic activity. For example, the world's old shield areas consist of crystalline rocks. Enclosed within these areas are many mineral deposits. One notable region is the Canadian Shield which was affected by volcanic activity over a thousand million years ago. This shield area is a real storehouse of mineral wealth. Gold can be obtained from Kirkland Lake, nickel and copper at Sudbury, silver and gold at Cobalt, and quite recently vast deposits of iron have been found near Schefferville on the Labrador border.



The farmers are able to grow a wide variety of crops on the slopes of Etna.

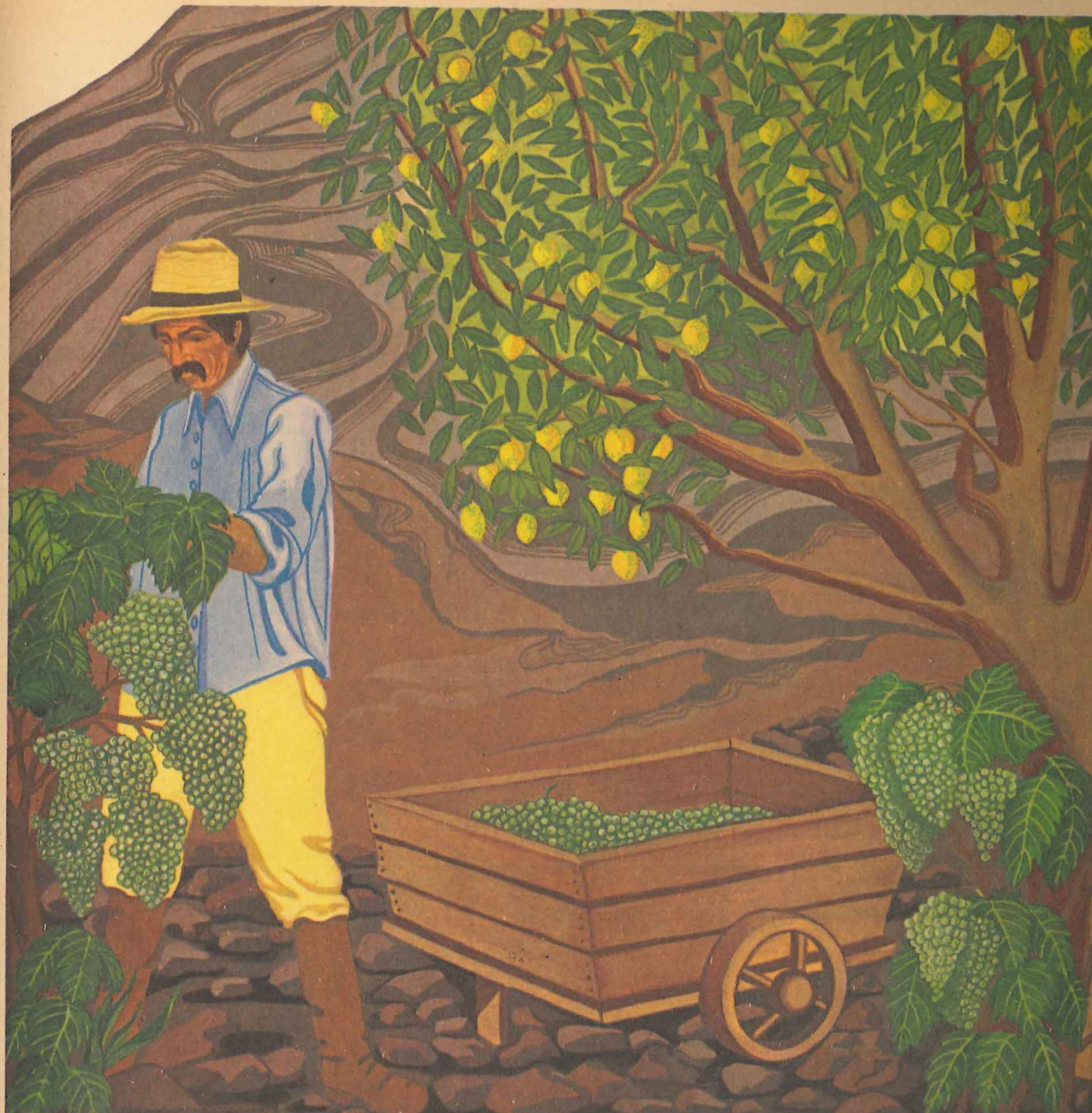
Economic Effects of Volcanoes

It is rather surprising to find large numbers of farms and even villages on the slopes of what appear to be dangerous volcanoes. The reasons are easily explained, as the lavas and ash will be turned into soil by weathering, and in some cases the resulting soils are rich and fertile. Also, the thought or fear of another eruption does not deter settlers. Most volcanic mountains which are densely settled are so large that local inhabitants considered it unlikely that future eruptions would occur on their area of the mountain.

Are volcanoes fertile?

Etna is one of the most famous volcanoes which is well populated. Here, in true Sicilian style, the farmers cluster in villages and walk out to their fields each morning. Although they are often quite poor, the farmers do grow cash crops in addition to growing some of their own foodstuffs. The cash crops which they grow in order to sell, vary according to elevation. This is because of the way in which the climate changes moving up the mountainside. At the lowest levels orange and lemon groves are numerous, but higher up they gradually give way to vineyards. The areas above the vineyards which have sufficient soil and water grow nuts, temperate fruit and cereals. Vegetables are grown at all levels for local consumption.

In spite of the area of rich soils and good farming on Etna, the entire mountainside cannot be utilised. At lower levels there are some areas of new lava which have not had time to be weathered and broken up to create soil. These areas are still covered by bare rock and are quite useless for farming. Also, all the land above 2,000 metres is too cold for farming. It is covered by snow for 3 or 4 months and is too rocky, with little or no soil.



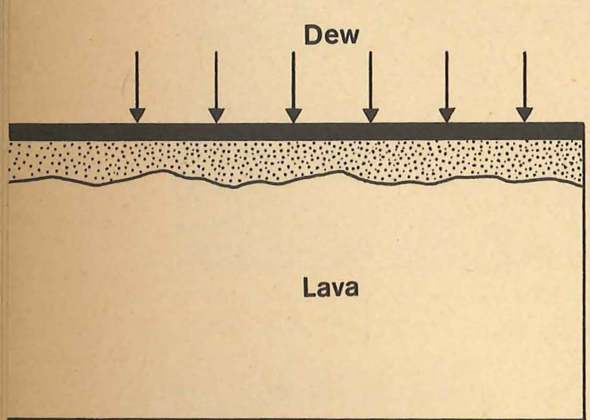
The new lava flows in the vineyards of Etna.

Etna is really typical of all volcanic areas, as the slopes of this mountain contain some rich farmlands, but many areas which are poor or even useless. Volcanic eruptions here and elsewhere may form acidic or basic rocks. Acidic rocks form acidic soils which are invariably poor for farming, even in Java, which has some of the most intensively farmed lands in the world. The rich farmlands of Java are only on the soils derived from basic lavas.

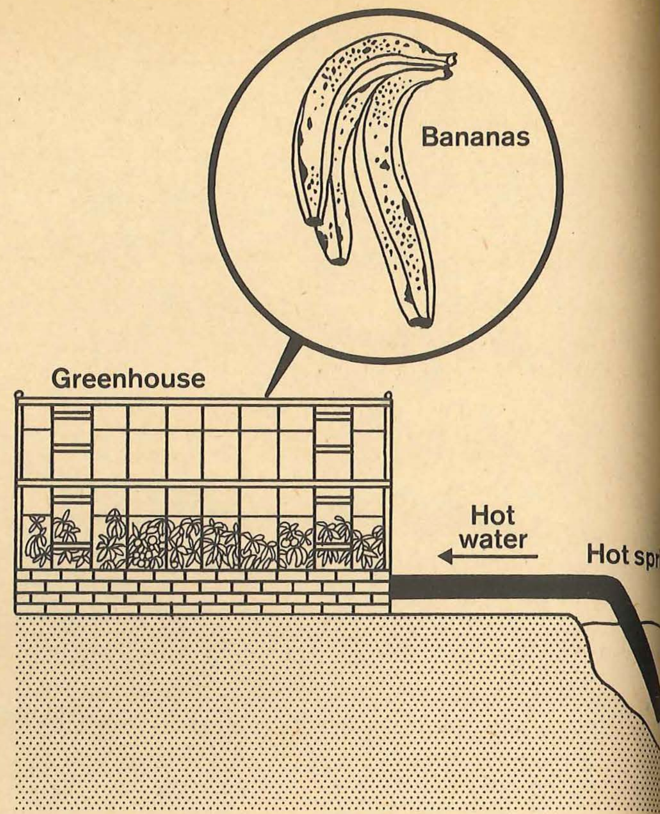
Basic lavas are potentially creators of good farming soil, but they do require several hundred years of weathering before sufficient soil has been formed. Furthermore, once the soil has been formed from the basic rock, the bases in the soil, that is the minerals which make the soil rich, are steadily washed out by water. If they are not replaced by the addition of fertiliser, even the rich basic soils will become poor in a few hundred years.

Therefore volcanic soils are not necessarily rich and more often than not are rather poor. In Britain volcanic soils occur on Dartmoor, Mull and elsewhere. Dartmoor is an acidic area and the soils are very poor. This is due to the granite rock and also the wet climate. Mull contains many basic areas with reasonable soils but here too the wet climate prevents good farming from taking place. So the climate is really a more important consideration than the quality of soils.

It is possible for the influence of humans to be greater than that of the climate or even the soils. One outstanding area where volcanic lands have been made productive is in the Canary Islands. The island of Tenerife has areas of good soil and because of the rain which falls on the highland, there is underground water available for irrigation. Many crops are grown, but bananas are particularly important.



The system of enarenado.



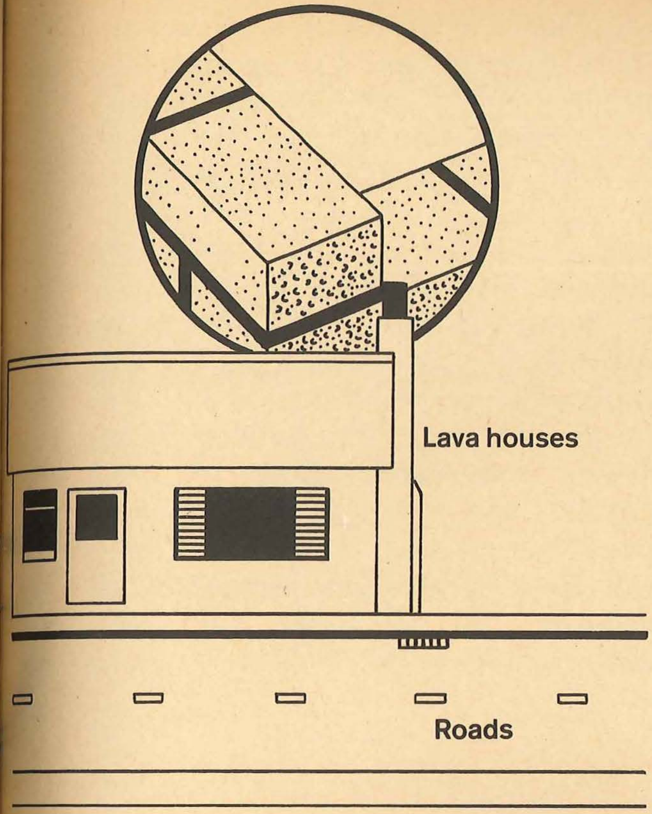
Hot springs enable bananas to grow in Iceland.

Is farming possible without water and soil?

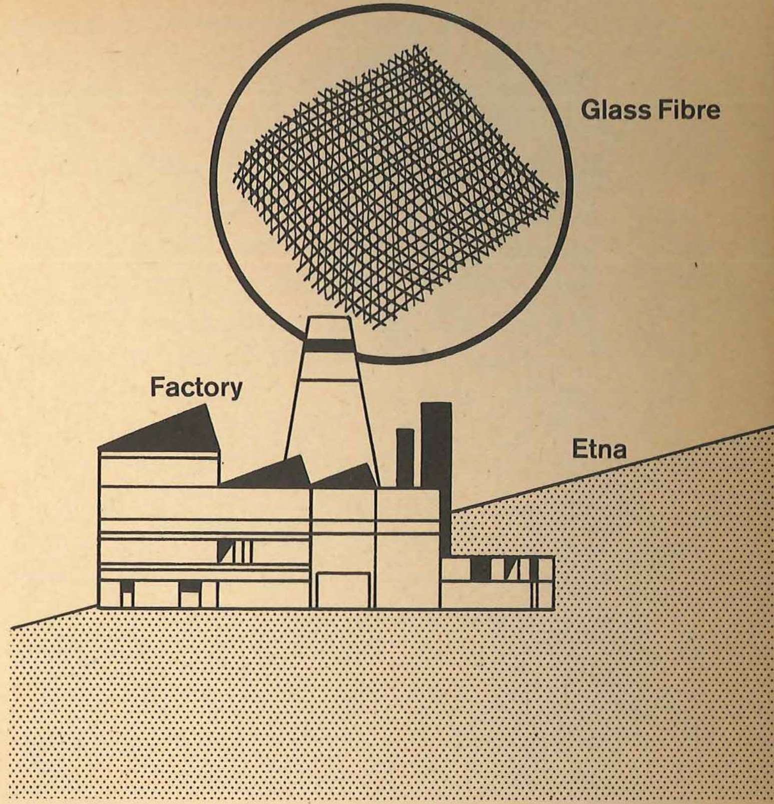
Parts of Tenerife have no soil and are generally useless for farming though in places an unusual type of farming is practised. This is the system of enarenado which originated in Lanzarote, but has been copied by some Tenerife farmers. In Lanzarote there is little soil and little rainfall, but in spite of these difficulties there is some commercial farming. The farmers have created fields on rugged expanses of lava by spreading a layer of soil on top of which they spread a layer of volcanic ash. The purpose of the volcanic ash is to soak up water from dew, as the annual supplies of rainfall are quite inadequate. By using this ingenious method, good crops of tomatoes, onions and potatoes can be grown in what was naturally a desert of lava. This provides an outstanding example of man's influence overcoming difficulties.

Can volcanoes provide central heating?

Volcanic areas may be economically quite useless, but in many cases do



Randazzo uses blocks of lava for building houses and surfacing the roads.



Geothermal power is used in factories in Italy.

have some importance. They may be utilised for sources of heated water; generation of geothermal power; supplies of sulphur or other minerals and precious stones; deposits of rich soil; or as tourist attractions.

Heated water has been utilised in Iceland as a form of central heating and the water from the hot springs heats greenhouses enabling tropical fruits such as bananas to be grown. The warm volcanic waters were used by Maoris to wash their clothes long before the first white settlers reached New Zealand.

A more advanced form of heating can also be obtained from the warm water and steam associated with vulcanism. Valves can be fitted to control the flow, enabling generators to be driven to produce electricity. This is geothermal power and has been utilised in Italy since 1913.

Most volcanic eruptions produce sulphur though only in small quantities. Large deposits occur in some old volcanic areas, for example southern Sicily. Volcanic activity also produces many other minerals and may create good building stone. Most volcanic areas make some use of the lava for constructional purposes in houses, walls or as road metal, and some Etna towns such as Randazzo even use it to surface the main roads. Also on the slopes of Etna there is a factory using lava to make glass fibre.

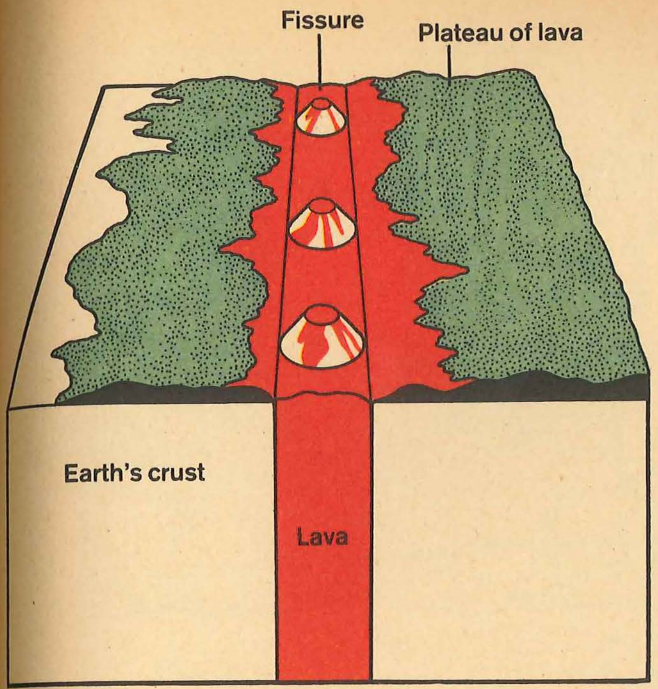
Volcanic soils have already been mentioned. In a few places, such as Mt. Etna, Java or Tenerife, there are areas with very rich and productive soils. In most places, however, volcanic rocks are devoid of soil or covered by only a thin layer which may be highly acidic and poor for plant growth.

Why do tourists flock to volcanic areas?

Of ever increasing importance in many parts of the world is the tourist industry. The presence of a volcano, especially if it is very large, or active, is a great advantage. Tourists are always eager to visit the scenes of disasters, as happened on Etna in 1971, when tourists flocked to the areas where lava overran vineyards and threatened houses. This volcano is also an attraction because it is so large and impressive, and has snow on the summit for much of the year. Mount Teide in Tenerife is an impressive and even higher volcano which has a snow cap for 3 or 4 months.

Lanzarote, another Canary Island, has a few tourist volcanic attractions. There is a stretch of 18th century lava studded with numerous small craters which resemble a lunar landscape. In the same area are a few hotspots where the ground is extremely hot. Only 60 centimetres below the surface the temperature reaches 400°C. Water can be thrown into a hole and will reappear as a small geyser within seconds. Also brushwood can be thrust into a hole in the ground and it bursts into flames almost immediately. Both of these localities are near a new restaurant which has an open barbecue utilising heat from subterranean sources. The restaurant is of course built with lava.

The lunar landscape of Lanzarote.



A fissure eruption.

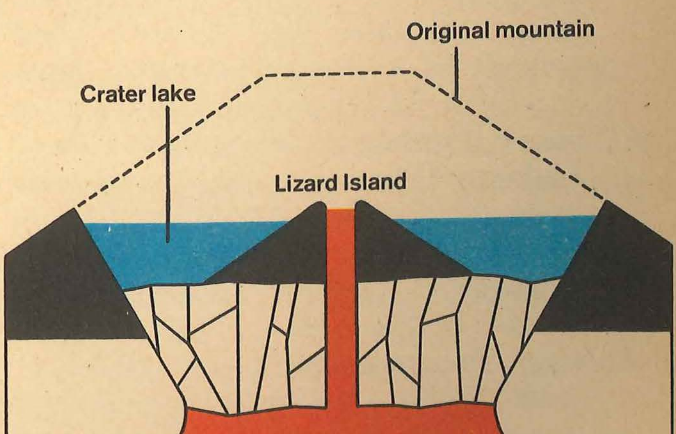

Fuji Yama.

Scenic Effects of Volcanoes

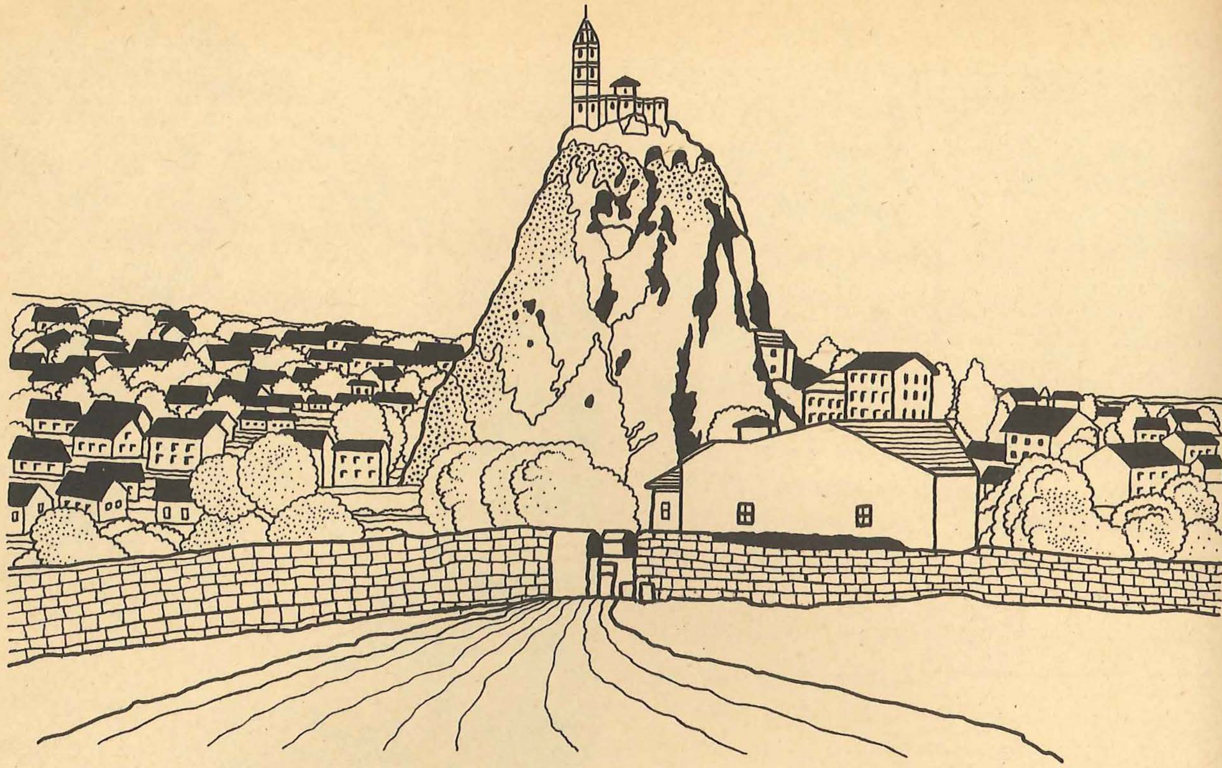
Are volcanoes always the same shape?

The largest effect igneous activity may have on scenery is in the formation of plateaux resulting from numerous fissure eruptions, such as in north-west U.S.A. Another outstanding landscape feature is a large mountain such as Etna or Teide.

Volcanic mountains will often form a nice cone shape because of the way in which successive eruptions pile up more material near the vent, so that the resulting hill is much higher in the middle. The steepness of the slopes will vary according to the type of material which has been ejected from the crater. If much sticky acidic lava has been erupted, the mountain is likely to be quite steepsided, whereas if free flowing basic lava is common, the cone will



Crater Lake in Oregon, U.S.A.



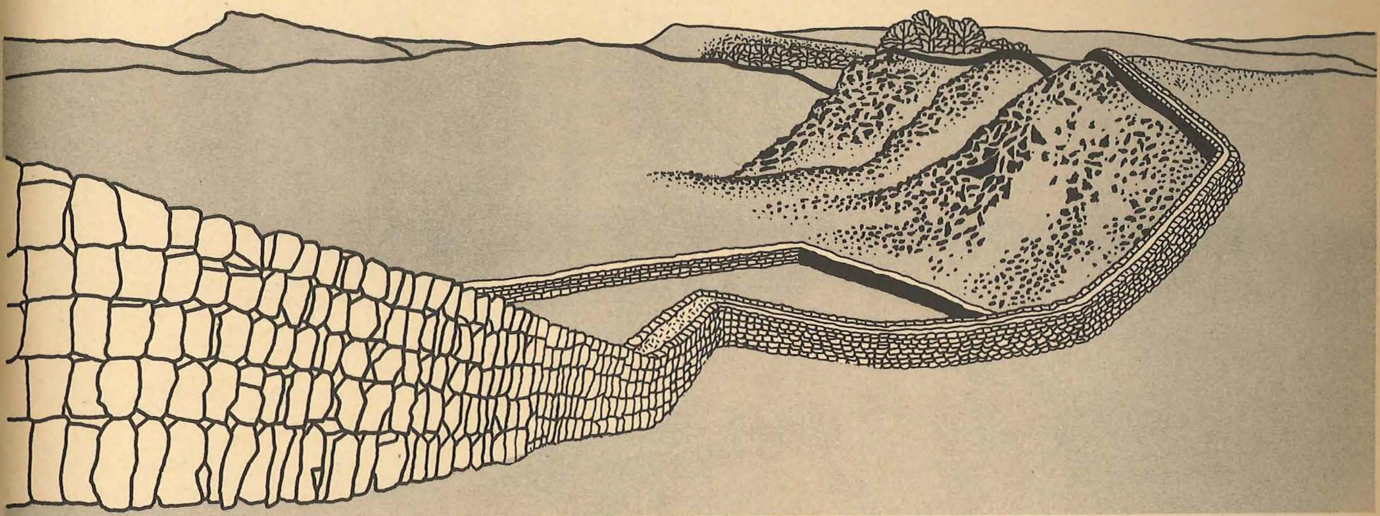
The Monastery at Rocher Aiguille.

have gentle slopes.

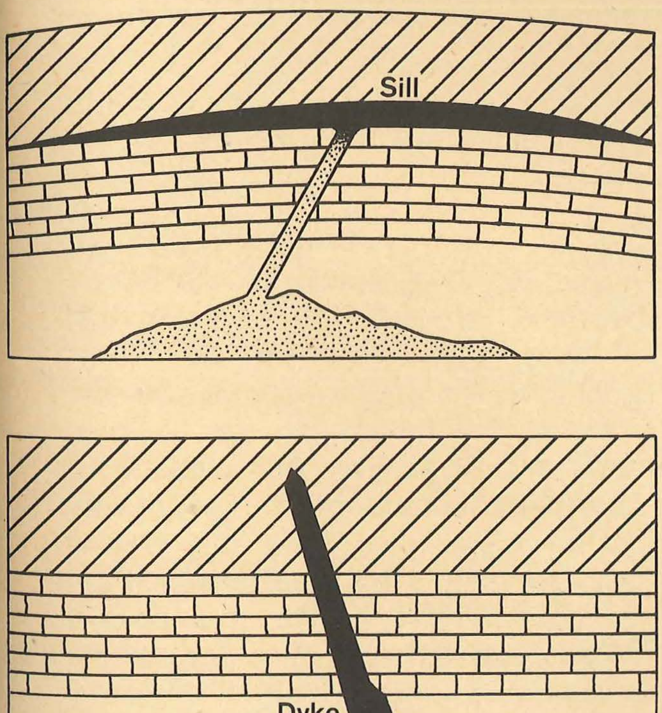
One of the most famous of conical volcanoes is Fuji Yama, or Mount Fuji in Japan, which last erupted in 1707. It is often used on Christmas cards or calendars because of its perfect conical shape and snow cap. Another good example of a cone, also with a snow cap for a few months of the year, is Mount Egmont in North Island, New Zealand. This was probably a marine volcano at first, and rivers flowing down the slopes deposited so much sediment in the sea that new land was formed building up the peninsula on which Mount Egmont now stands.

The top of a volcano may contain a crater which is normally quite small. Craters in dormant or extinct volcanoes may fill up with water to form lakes. The biggest example is called Crater Lake in Oregon, though this is so large that it is really a caldera and not a crater. Lake Toba in Sumatra is another large crater lake. Lake Bolsena in Italy and the lakes of the Eifel district in western Germany are other examples.

When volcanoes become extinct, the old vent remains filled with lava which is more compact and resistant to erosion than the mass of the mountain. After a few thousand years of erosion, most of the mountain will have been removed, but much of the tough lava in the old vent will remain as a pinnacle of rock. These rocks are called volcanic plugs or necks, and because several occur near Le Puy in the Massif Central of France, they are also called puys. One very steep needle of rock near Le Puy is called Rocher Aiguille (needle rock), and has a monastery located at the top. Volcanic necks occur even in Britain, for example in Edinburgh, where the castle is situated



Hadrian's Wall follows a sill for several miles.



The structures of: (a) a sill; (b) a dyke.

on what was the crater of a long extinct volcano.

Will intrusions of lava affect the scenery?

Thin sheets of lava are often intruded between or through existing layers of rock, or they may fill up cracks which have been caused by rocks stretching. These thin sheets are called sills if they are nearly horizontal, or dykes if they are nearly vertical. If they reach the surface, they normally form ridges as they are more resistant to erosion than the surrounding rocks. Great Whin sill extends from north Yorkshire to reach the sea at Bamburgh and the Farne Islands, Bamburgh Castle owes its prominence to its situation on the basalt sill. For a few miles, Hadrian's Wall runs along the top of the sill because it provided a good defensive position and vantage point.

Victoria Falls on the Zambesi.

Sills and dykes are usually more resistant than adjacent rocks and therefore they will often form waterfalls. Wherever rivers cross these resistant strips of lava, waterfalls are likely to occur. Examples of waterfalls caused by intrusions of lava include High Force on the river Tees, the Yellowstone Falls in U.S.A. and Victoria Falls in southern Africa.

What volcanic effects can be seen in Britain?

In Britain, in addition to the volcanic plugs there are quite a few places with igneous rocks. They occur in large areas of north-west Scotland, especially in the islands such as Skye, Mull and Arran. Skye contains a variety of igneous rocks but the most rugged mountains, the Cuillins, are made of gabbro. Arran also contains plutonic rocks but they are mostly granites. Mull contains a little granite too, but mainly has basalts, which are more than 1,800 metres in thickness. Such a large amount of rock probably represents a large number of eruptions which occurred during the Miocene period. At this time, Iceland, northern Ireland and western Scotland were all very close together and vast quantities of lava appeared as Greenland and Europe drifted apart. They can be seen in Iceland, Antrim Mountains and elsewhere.

Further south there are other and much older lavas in the Lake District and Snowdonia. The Lake District contains areas of slate, a metamorphic rock, and also the lavas. Hills on both rocks reach over 930 metres but the slate hills are less steep and rugged than the hills which are made of tough lava. Skiddaw reaches a height of 930 metres, and is made of rocks called Skiddaw slates. It has quite a gentle slope on its west-facing side overlooking the town of Keswick. The other high peaks are Helvellyn (950 metres) and Scafell (970 metres) both of which are made of Borrowdale lavas which often form steep rocky crags.

In the extreme south are the granite areas of Dartmoor, Bodmin and Land's End. These have formed rather bleak moorland areas, covered with thin acidic soil and rather poor vegetation. In fact, all the igneous areas of the British Isles are rather unproductive agriculturally, and in most cases have formed rather rugged hills.

The position of Iceland, Ireland and Scotland in the Miocene period.

Place	Main Rocks
Skye	Gabbro
Mull	Basalt
Arran	Granite
Lake District	
Skiddaw	Skiddaw slates
Helvellyn, Scafell	Borrowdale lavas
Snowdonia	Older lavas
Dartmoor, Bodmin, Land's End	Granite

The volcanic rock areas in England.

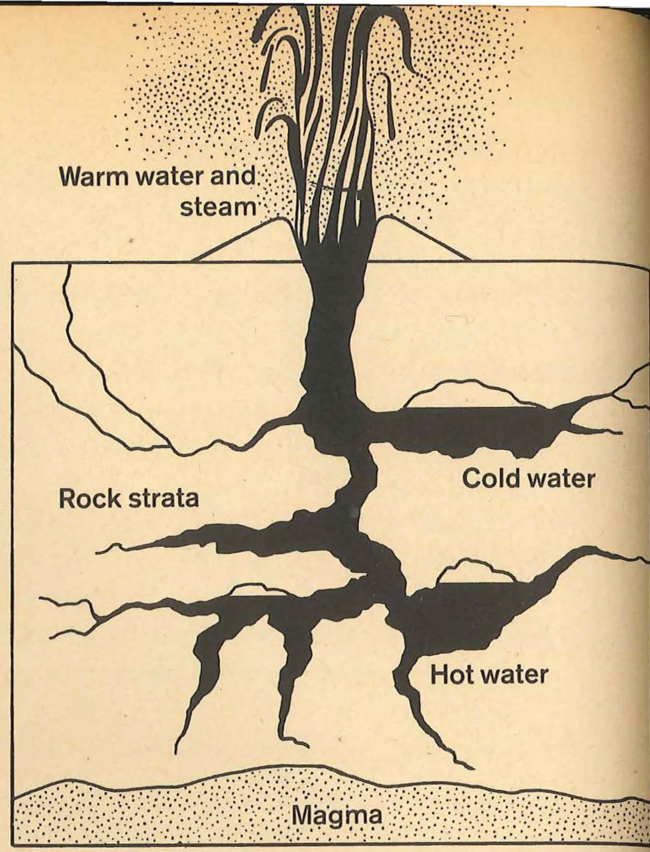
Phenomena associated with Volcanic Activity

What are water volcanoes?

Some quite large volcanoes only pour out smoke, steam or gases. Mount Erebus in Antarctica is continuously smoking. Much smaller, though related to volcanoes, are phenomena which erupt water, smoke or gas. These are geysers, fumaroles or solfataras. They do not erupt from true volcanoes but merely through small cracks or fissures.

All these phenomena are associated with volcanic areas and are possibly the last dying remnants of much greater activity. They occur in areas with high ground temperatures plus numerous cracks or fissures in the rock.

Geysers are fountains of steam and warm water, often rich in chemicals. Water droplets trickle into a fissure which extends down to underground caverns where water can accumulate. Volcanic heat warms the water and the deeper water becomes hotter than that near the surface. The effect of pressure adds to these differences in temperature. The water at the bottom of the fissure may reach boiling point and when it does so, it shoots out all the water near the top of the fissure. Thus the water which squirts out in the fountain is warm, but is not the water which reached boiling point. Geysers occur in many places, notably North Island, New Zealand, Iceland and Yellowstone National Park in U.S.A., all of which have become important tourist areas. The original geyser which gave its name to them all is Great Geysir in Iceland. It now only erupts at irregular intervals but used to reach 50 metres. Iceland contains the most active geyser area in the world, with 1,000 springs within 2·5 square kilometres.



The cause of a geyser.

Another very active area is Yellowstone which contains 100 geysers and 3,000 hot springs. Most famous is Old Faithful which erupts every 65 minutes. This fountain reaches a height of 40 metres and pours out 59,000 litres of water per eruption. Waimangu geyser in New Zealand used to send water more than 300 metres, but has now ceased activity. Many geysers contain chemicals and so deposits may be laid down all round the fissure.

Fumaroles and solfataras are similar to geysers but fumaroles pour out gas and steam, and solfataras emit sulphurous fumes. They both occur in areas with active volcanoes, coming out from small subsidiary vents, but they also occur where there is no violent activity.

Fumaroles may give off hydrochloric acid, sulphur and chlorides, and are generally jets which erupt under pressure. In Italy, near Larderello, fumaroles are used to drive generators to produce electricity. Fumaroles are most numerous in the Valley of 10,000 Smokes in Alaska.

Quietly erupting fumaroles which emit sulphurous vapours are called solfataras. They take their name from Solfatara in the Phlegraean Fields near Naples. The edge of the vent is usually encrusted with sulphur and possibly other minerals too.

Similar to geysers though rather weaker are hot springs and mud volcanoes. In geysers, heat is not lost at the surface as quickly as it is acquired below ground, hence the build up of heat which ends in eruptions. Hot springs do not erupt as the water temperature remains constant because heat is lost as quickly as it is gained. Hot springs occur in all the same areas with geysers, plus many additional localities. Britain has examples of hot springs at Bath. The water emerges from underground at a temperature of 50°C, at a rate of over 2 million litres daily. The water was first used by the Romans, and is still utilised for rheumatic and orthopaedic treatment. Hot springs have given rise to health resorts in many other places such as Japan and France.

Can volcanoes provide electricity?

Underground heated water has been used for many centuries as, for example, by the Maoris and in Iceland. It has also been utilised in spas such as Bath. Greenhouses in Iceland have been warmed since 1924, and volcanic heated water now supplies most of Reykjavik's needs, including open-air swimming pools. The most modern and efficient method of utilising the subterranean heat is by harnessing it to drive turbines in order to generate electricity. This electricity is called geothermal power.

Geothermal power has been produced in Italy from fumaroles, and in New Zealand from geysers. In Italy, the world's first geothermal station was opened at Larderello in Tuscany in 1913. This area is thought to have inspired Dante's vision of inferno. In New Zealand there are geothermal power stations at Wairakei and Waiotapu. Wairakei, 9 kilometres north of Lake Taupo, uses bore holes to tap the underground supplies of steam. The steam is piped into the generating station which produces electricity. Although the steam has been utilised since 1958, there are no signs of supplies diminishing, though there has been a little subsidence presumed to be due to the removal of water. At Wairakei there is a new hotel, the Wairakei Thermal Hotel, which utilises the local supplies of heat for its needs, including the swimming pool.

Volcanic waters can be utilised without the need for them to be turned into electricity. This applies to greenhouses in Iceland and a hotel in New Zealand as already mentioned. Also there is a pulp and paper factory in New Zealand which uses this very cheap source of energy. Japan, Hungary and U.S.S.R. all use hot water for heating, and many places in Central America, especially San Salvador, Chile, Kamchatka and Ethiopia, are beginning to harness some of their potential. There are trial bores in Imperial Valley in southern California and the area known as Geysers Field in northern California produces electricity.

Are earthquakes related to volcanoes?

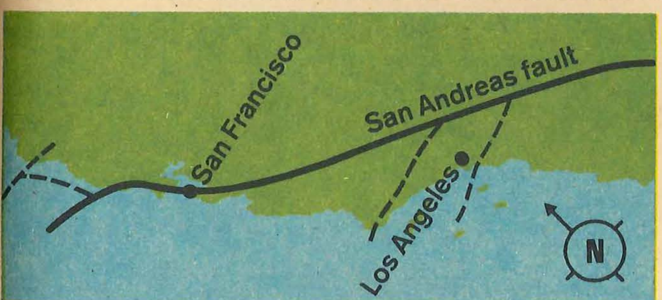
The rocks which make up the earth's crust are somewhat similar to a twig or a branch on a tree. If a branch is subjected to pressure it will bend steadily until eventually it will snap. The layers of

Geysers are very exciting to watch.

rock also bend under the effects of gentle pressure but eventually, if the pressure is too great or too sudden, the rocks crack.

The effect of this sudden movement just below the surface, or in some cases several miles underground, is to send shock waves travelling through the rocks. These waves or vibrations are similar to the ripples to be seen on a pond after a stone has been thrown in.

The distribution of earthquakes is very similar to that of volcanoes which is understandable, as they are both caused by similar factors, basically the movement of the earth's plates and the subterranean heat. Though there is this close connection, the most severe earthquakes tend to occur where there are no volcanoes. Perhaps the volcanoes act as safety valves elsewhere. 80 per cent of all earthquakes occur in the circum Pacific belt, in association with volcanoes and young fold mountains. One of the most famous earthquakes in this area occurred at San Francisco in 1906. This earthquake was associated with the San Andreas fault which has been carefully studied by American geologists in recent years. It has been discovered that the edges of two of the world's plates run in a north-south line through San Francisco and much of California. The line separating the two plates is called the San Andreas fault. It is visible from the air in several places, where the land to the east of the fault is moving south, and the land to the west is moving north at the rate of 6 centimetres per annum. This movement of plates alongside the fault line is similar to two



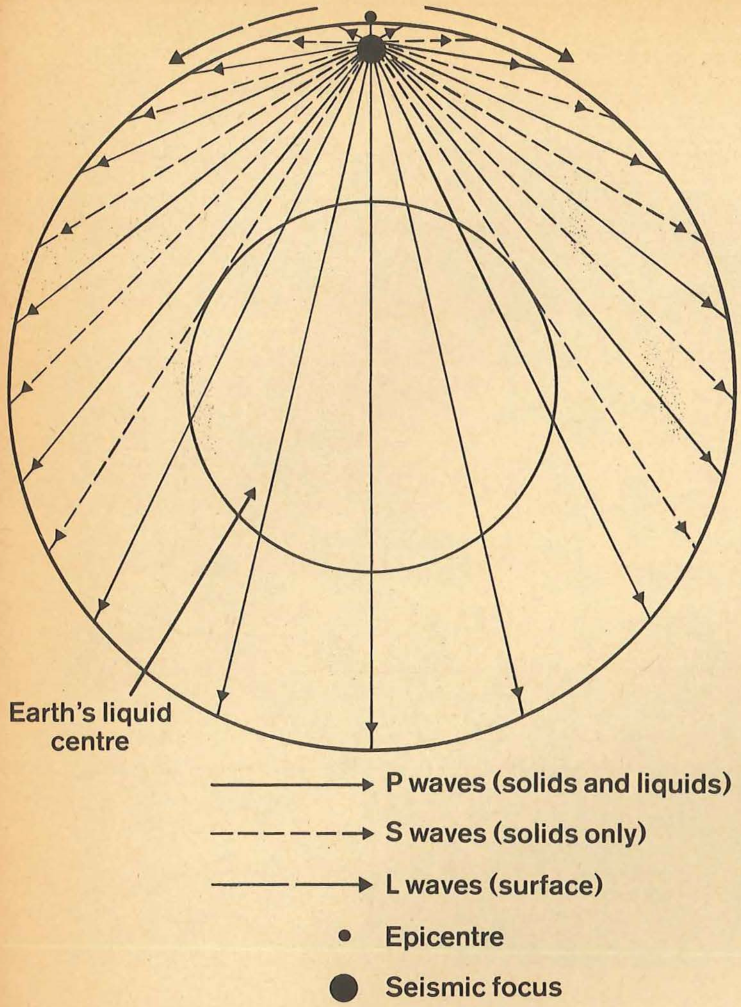
The San Andreas fault caused the earthquake which destroyed San Francisco in 1906.

trains passing each other on opposite lines. It is likely that in the near future there will be a big movement along the San Andreas fault, which could be disastrous. In 10 million years, Los Angeles will have moved to where San Francisco is now located.

San Andreas may cause a disaster in the future, and has already caused a major one in the past. Other earthquake disasters have been quite numerous but amongst the largest have been the China earthquake of 1556, when threequarters of a million people died, and the Sagami Bay earthquake in 1923 when a quarter of a million died. In addition to the danger from shaking, there is also the tsunami. The Lisbon earthquake of 1775 caused a 12 metre tsunami. This earthquake even caused the water to fluctuate 1 metre on Loch Lomond.

How are earthquakes recorded?

The starting point of the tremor which constitutes the earthquake is called the seismic focus and from here the shock waves travel out in all directions. The effect of the waves becomes less with increasing distance, but large earthquakes may be recorded thousands of kilometres from their place of origin by delicate instruments called seismographs. There are up to a million earthquakes each year, so seismographs are kept busy.



Earthquake waves move out from the seismic focus.

The seismograph consists of a heavy weight suspended so that it remains vertical even if the earth's crust is shaken. The seismograph box will move and a nib on the end of the weight will record the tremor. A mark will of course be made if the building is shaken by the proximity of lorries, dumpers, bulldozers or heavy machinery. As these movements are known and noted, they can be ignored on the seismic records, but it will clearly be more sensible to place the seismograph in a quiet isolated spot where there will be no man-made shaking.

Why are there three tremors during earthquakes?

The seismograph records all the shaking, and in earthquakes there are three types of waves, separated only by a matter of seconds. The rocks crack and sometimes move slightly. The movement is usually only a few centimetres though 15 metres was recorded in the great Alaskan earthquake of 1899.

The three types of waves which result from the shock are called the P, S and L. P and S waves both move out in all directions from the seismic focus. The P waves are the fastest and they move in a pulsating fashion similar to radio waves, and these are able to pass through solids and liquids. S waves move in a sideways or transverse type of movement, rather similar to the quivering movement which can be created by placing a piece of rope on the ground then picking up one end of the rope and shaking it. A rather snake like movement will proceed along the rope. These S waves are only able to pass through solids.

The difference between these two waves has enabled geologists to confirm that the centre of the earth has a liquid core, because in very large earthquakes, which should send waves right across the earth, there is a blind spot on the far side of the liquid core, which records no S waves.

P and S waves eventually reach the surface where they become L or longitudinal waves. These travel along the surface with decreasing violence with increased distance. The point on the crust directly above the seismic focus is called the epicentre and here the shaking effect will be most violent. In big earthquakes houses may collapse, though further away from the epicentre lesser damage such as broken windows may result. The longitudinal waves are the last of the three to arrive. It is these waves which cause damage and therefore affect us most.

Era	Period		Length of period in millions of years	Millions of years ago
Kainozoic era 65 Million years	Quaternary		2	
	Tertiary	Pliocene	5	7
		Miocene	19	26
		Oligocene	12	38
		Eocene	27	65
Mesozoic era 160 Million years	Cretaceous		71	136
	Jurassic		57	193
	Triassic		32	225
Palaeozoic era 345 Million years	Permian		55	280
	Carboniferous		65	345
	Devonian		50	395
	Silurian		40	435
	Ordovician		65	500
	Cambrian		70	570
	Pre-cambrian era			

A GEOLOGICAL TIME SCALE

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